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Hygroscopic growth of atmospheric aerosol particles based on lidar, radiosonde, and in situ measurements: Case studies from the Xinzhou field campaign

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ABSTRACT

Lidar, radiosonde, and ground-based in situ nephelometer measurements made during an intensive field campaign carried out from July to September 2014 at the Xinzhou meteorological station were used to determine the aerosol hygroscopic growth effect in a cloud-capped, well-mixed boundary layer. Aerosol hygroscopic properties at 355 and 532 nm were examined for two cases with distinct aerosol layers. Lidar-derived maximum enhancement factors in terms of aerosol backscatter coefficient derived using a relative humidity (*RH*) reference value of 85% were 1.19 at 532 nm and 1.10 at 355 nm for Case I and 2.32 at 532 nm and 1.94 at 355 nm for Case II. To derive the aerosol particle hygroscopic growth factor at specific *RH* values, the Kasten and Hänel models were used. A comparison of the goodness of fit for the two models showed that the Kasten model performed better. The hygroscopic growth curve for $RH > 90\%$ was much steeper than that for *RH* in the range of 85–90%. The slopes of the lidar-derived enhancement factor curve (measured from 85% to 95% *RH*) and the nephelometer-derived enhancement factor curve (measured from 40% to 62% *RH*) in Case I show similar trends, which lends confidence to using lidar measurements for studying aerosol particle hygroscopic growth. Data from a ground aerosol chemical speciation monitor showed that the larger values of aerosol hygroscopic enhancement factor in Case II corresponded to greater mass concentrations of sulfate and nitrate in the atmosphere.

1. Introduction

The importance of atmospheric aerosols in earth's climate has been widely recognized [1,2]. Aerosols affect solar radiation directly by scattering or absorbing solar radiation and indirectly by acting as cloud condensation

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nuclei (CCN), which is closely related to aerosol hygroscopicity [1,3,4]. Likewise, the swelling of aerosols due to water vapor uptake enhances their ability to scatter solar radiation. In this way, aerosol hygroscopic growth plays an important role in the earth's radiation budget [5–7].

Numerous studies over the past years have investigated the hygroscopic growth effect on aerosol optical and microphysical properties in terms of the hygroscopic growth factor, or $f(RH)$ where RH is the relative humidity. Much of the recent research has been done using data collected from humidified nephelometers [3,8] and humidified tandem differential mobility analyzers (HTDMAs) [9–11]. However, these instruments have their limitations. For example, because of their experimental set-up, humidified nephelometers cannot expose air samples to $RH \geq 85\%$ without risking condensation on their chilled mirrors, which would result in spurious measurements. HTDMAs have the advantage of being able to size-select aerosol particles before exposing them to a controlled humidity environment, but have difficulties in reaching RH above ~90%. It is the RH range of 85–100% that is of more pertinent to the ability of aerosols to act as CCN. Another limitation of these instruments is that they can change aerosol properties in the process of drying air samples and re-humidifying them again to a certain RH level. Aerosol particles can also be lost in the sampling line.

Lidar remote sensing is an alternative way to study aerosol hygroscopicity. One advantage of using lidars is that measurements can be made at ranges close to saturation. Another advantage is that the enhancement in backscatter due to changes in RH is measured under ambient and unperturbed atmospheric conditions. However, because aerosols sampled by a lidar are not controlled in any way, lidar applications for hygroscopic growth studies must be limited to cases where the same type of aerosol exists in at least a portion of a profile and where RH values vary widely. Observed differences in aerosol properties can be then be attributed primarily to water uptake as RH increases. Many studies have focused on using lidars to study aerosol hygroscopicity with promising results. In general, RH profiles are required for the analysis of aerosol hygroscopicity. Most of these studies, though, make many assumptions to obtain RH profiles [8,12] or use quite distant radiosonde measurements that are not collocated with the lidar used [13]. Besides, few studies have examined the association between lidar-derived aerosol hygroscopic properties and in situ aerosol chemical composition obtained using a ground-based aerosol chemical speciation monitor (ACSM).

In this study, a methodology to investigate aerosol hygroscopic growth primarily based on a three-wavelength Mie polarization Raman lidar (TMPRL) is developed and applied to data collected at the Xinzhou meteorological station in China. A description of the field campaign and the instruments used is given in Section 2. Section 3 describes the methodology and Section 4 presents the results. Conclusions are given in Section 5.

2. Field campaign and instrumentation

An intensive field campaign was carried out from July to September 2014 at Xinzhou in Shanxi Province (Fig. 1). The measurement site was situated at the Xinzhou meteorological station (38.39°N, 112.7°E, at an elevation of 870 m above sea level, or ASL), which is located to the west of the city. The land surrounding the site is a mix of agricultural, residential, and industrial. The temperate continental monsoon climate over this area, along with the increase in local emissions of anthropogenic aerosol particles, may have a strong impact on regional air quality and climate.

For a better understanding of the impact of aerosol hygroscopic growth on aerosol scattering properties, a TMPRL was used. The TMPRL, a self-contained, fully automated system designed for continuously measuring aerosol optical properties such as the extinction

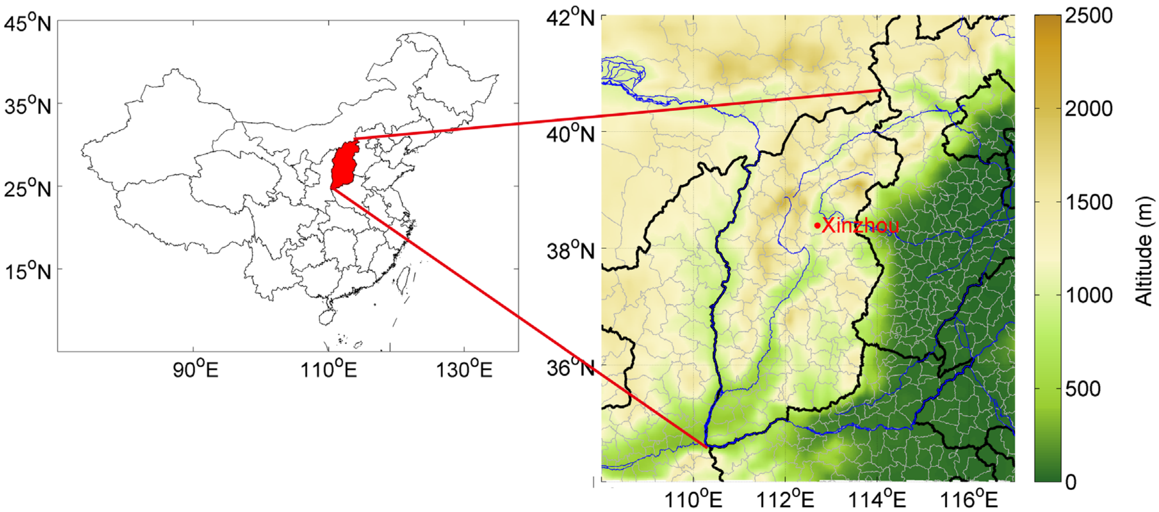

Fig. 1. Left panel: Map showing Shanxi Province in China (red shaded area). Right panel: Location of the experimental site (red solid circle). The altitude is height above sea level. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)