한국환경과학회 가을 학술발표회지 제14권(제2호), 33~36, 2005
Proceedings of the Korean Environmental Sciences Society Conference, Nov, 18~19, 2005

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Investigation of the hygroscopic properties of mineral dust, pollution and biomass burning aerosols

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1. Introduction

This paper describes the use of measured aerosol size distributions and size-resolved hygroscopic growth to examine the physical and chemical properties of several particle classes. The primary objective of this work was to investigate the hygroscopic properties of a range of ambient aerosol types measured in a number of different locations. The tool used for most of these analyses is a differential mobility analyzer / tandem differential mobility analyzer (DMA / TDMA) system developed in our research group. To collect the data described in two areas of this study, an aircraft-based version of the DMA / TDMA was deployed to Japan and California. The data described in two other study were conveniently collected during a period when the aerosol of interest came to us. Instruments similar to the DMA / TDMA system described here have been used by a number of research groups throughout the world. The unique aspect of this analysis is the use of these data to isolate the size distributions of distinct aerosol types in order to quantify their optical and cloud forming properties.

I used collected data during the Asian Aerosol Characterization Experiment (ACE-Asia) to examine the composition and homogeneity of a complex aerosol generated in the deserts and urban regions of China and other Asian countries. An aircraft-based tandem differential mobility analyzer was used for the first time during this campaign to examine the size-resolved hygroscopic properties of particles having diameters between 40 and 586 nm. Asian Dust Above Monterey (ADAM-2003) study was designed both to evaluate the degree to which models can predict the long-range transport of Asian dust, and to examine the physical and optical properties of that aged dust upon reaching the California coast. Aerosol size distributions and hygroscopic growth are measured in College Station, TX to investigate the cloud nucleating and optical properties of a biomass burning aerosol generated from fires on the Yucatan Peninsula.

2. In situ aerosol growth factor measurements

Hygroscopic properties of particles have been examined through the use of humidified

TDMA systems in several areas. A summary of recent applications is included in Cocker *et al.* (2001). A humidified TDMA consists of two DMAs in series, between which the aerosol is exposed to an elevated RH. The voltage applied to the first DMA is fixed to select a monodisperse aerosol. Following exposure to high RH, the initially monodisperse aerosol enters the second DMA in which the applied voltage is continuously varied to characterize the resulting size distribution of the humidified aerosol. In this way, the change in particle size due to interaction with water vapor is determined. The hygroscopic growth factor (GF) distribution of the aerosol is described by the resulting size distribution with the final particle size following exposure to high RH (D_p) normalized with respect to the initial dry particle size, D_p^*(Fig. 1).

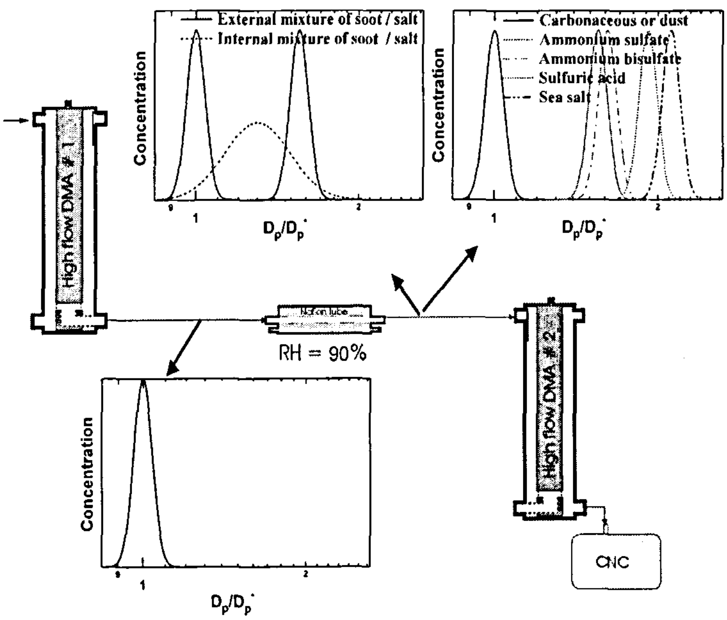

Fig. 1. Simplistic representation of the behavior of distinct aerosol types as measured by a TDMA.

3. Results and discussions

In this paper, I describe a method for examining the hygroscopic properties of specific classes of aerosols. The underlying objective of this work is to contribute to an improved understanding of the direct and indirect effects of aerosols on climate. I used data collected during the Asian Aerosol Characterization Experiment (ACE-Asia) to examine the composition and homogeneity of a complex aerosol generated in the deserts and urban regions of China and other Asian countries. An aircraft-based tandem differential mobility analyzer was used for the first time during this campaign to examine the size-resolved hygroscopic properties of particles having diameters between 40 and 586 nm. The size dependence of the hygroscopic behavior of the aerosol is summarized in Fig. 2. In these graphs, the lower and upper edges of the boxes represent the 25^{th} and 75^{th} percentile values, respectively, while the lower and upper whiskers represent the 10^{th} and 90^{th} percentiles, respectively. The horizontal lines near the center of each box represent the media. The study location offered a unique opportunity to investigate the impact of anthropogenic emissions on naturally-generated dust particles. Hygroscopic growth factors at 90% RH typically exceeded 1.4, suggesting the soluble fraction of the aerosol was relatively high. The mean standard deviation of the measured growth factor distributions, which is related to the compositional heterogeneity of the aerosol, increased with increasing particle size, although this trend often reversed for the largest particles considered. Overall, hygroscopicity was observed to increase with proximity to the surface, and with increasing size. One cause of the observed height dependence is the frequent presence of non-hygroscopic dust particles at higher levels that, closer to the surface, were either not observed or had been coated with soluble compounds such as sulfate.

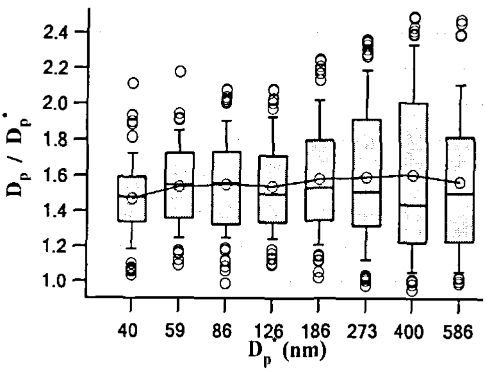

Fig. 2. Box plots showing the median growth factor for all TDMA measurements made during the 12 flights considered here.

Asian Dust Above Monterey (ADAM-2003) study was designed both to evaluate the degree to which models can predict the long-range transport of Asian dust, and to examine the physical and optical properties of that aged dust upon reaching the California coast. During several of the flights, distinct layers of dust that had been preserved during the transit across the Pacific were observed. These layers were typically present between 2 and 4 km asl. By coupling the measured size distributions with a size-dependent fractional categorization based on the hygroscopic growth measurements, independent size distributions for the dust and other aerosol types were created. Within the sampled layers, both the overall mass concentration and light extinction coefficient were dominated by the larger dust particles. Light scattering coefficients predicted based on the measured size distributions compared well with those directly measured with a nephelometer. The calculated mass extinction efficiency of the dust aerosol was somewhat higher than that observed during other studies suggesting that the size distribution had shifted towards smaller size as gravitational settling removed the largest dust particles.

Aerosol size distributions and hygroscopic growth measured in College Station, Texas to investigate the cloud nucleating properties of a biomass burning aerosol generated from fires on the Yucatan Peninsula. Whereas most other studies designed to investigate biomass burning aerosol have been conducted close to the aerosol source, the data described in this chapter provide details of the properties of an aged smoke aerosol. Measured aerosol size distributions and size-resolved hygroscopicity and volatility were used to infer critical supersaturation distributions of the distinct particle types that were observed during this period. The average inferred CCN concentrations were 869, 1918, and 2206 (cm^{-3}) at 0.15, 0.5, and 1.0% critical supersaturations, respectively. The predicted CCN concentrations were used in a cloud model to determine the impact of the different aerosol types on the expected cloud droplet concentration. For certain aerosol measurements and cloud updraft velocities, predicted cloud droplet concentrations were lower when the observed sulfate aerosol was considered together with the biomass burning aerosol relative to that when only the biomass burning aerosol was considered. By suppressing activation of the less hygroscopic biomass burning particles, pollution aerosols may actually help preserve the smoke aerosol by reducing wet deposition rates. Furthermore, this represents a scenario in which pollution aerosol may cause a slight reduction in cloud albedo.

References

Cocker, D. R., N. E. Whitlock, R. C. Flagan, and J. H. Seinfeld, Hygroscopic Properties of Pasadena, California Aerosol, Aerosol Science and Technology, 35, 637-647, 2001.