A comparative study as a quality assurance of stationary and portable hand-held ultrafine particle monitors

POHL, T., FISCHER, C., HEWELING, G., BÖHLKE, C., WEBER, K.
Laboratory for Environmental Measurement Techniques
University of Applied Sciences Duesseldorf (HSD)
Muensterstr. 156, 40476 Duesseldorf
GERMANY

konradin.weber@hs-duesseldorf.de http://www.hs-duesseldorf.de

Abstract: In this study we investigated the performance of two portable hand-held measurement devices (Testo DiSCMini, Grimm NanoCheck) under real environmental conditions at an area on the new campus of the University of Applied Sciences Duesseldorf, which was influenced by construction activities and traffic. The values were compared to the data from a freshly calibrated SMPS (Grimm SMPS+C) as a reference system. The SMPS measured the particle number concentration as well as the particle number size distribution in a range from 5 nm to 350 nm. This was done as a quality assurance for the use of these portable devices for other measurement campaigns for detecting the particle number concentration in mobile applications by e.g. unmanned aerial systems, bicycles, or small aircraft. The results show a good correlation between all the systems. The agreement between the reference system and the NanoCheck was really good, but lower between the DiSCMini and the reference system. Due to the good correlation the data could be post processed with a correction function to reduce the deviation. Finally, it can be stated, that both systems work well under environmental conditions and are well suited for the mobile use for the investigation of ultrafine particle concentration.

Key-Words: comparative measurements, ultrafine particle, UFP, SMPS, DiSCMini, NanoCheck

1 Introduction

Pollution causes unhealthy environments and therefore is still one of the major risks on human health today. Diseases caused by pollution were estimated of about 9 million deaths worldwide [1]. The World Health Organization (WHO) estimates, in a study from 2012, that the impact of ambient air pollution only, more precisely the air pollution from particulate matter, is responsible for 3 million deaths worldwide [2]. Particulate matter or aerosols in ambient air vary in their size from a few nanometers up to several ten micrometers.

Ultrafine particles or $PM_{0.1}$ are aerosols with a diameter smaller than 100 nanometers and have a special risk on human health. Because of their small size down to a few nanometers, they get very deep into the respiratory tract were they deposit. There they are able to pass through cell membrane [3] or get through the alveolus into the blood circulation and are distributed throughout the whole body [4]. Further criteria for health relevance of ultrafine particles are their shape, the water solubility and their high specific surface. Particles of substances with higher water solubility get easier into lung fluid and therefore can be better removed. The high specific surface of the ultrafine particles often adsorbs toxic substances like volatile organic compounds or polycyclic hydrocarbons, which are thus deeply embedded into the lungs.

Scanning mobility particle sizers (SMPS) systems are state of the art techniques to measure the particle number size distribution (PNSD) in the sub-micrometer region and were used for several investigations of different sources like road, ship and air traffic emissions or other anthropogenic sources as well as natural sources. In the past years several efforts were done to assure a high data quality using SMPS systems [5,6].

A disadvantage of these systems is their relative big size and weight, so that they cannot be used easily to measure the spatial distribution of ultrafine particles. For mobile measurements e.g. by bike, car or airborne platforms like unmanned aerial systems or small aircrafts [7,8] portable devices like the NanoCheck from Grimm Aerosoltechnik, the DiSCMini from Testo or the nanoTracer from Aerasense/Phillips were developed. They are small and light weighted for these kind of studies, but measure only the size integrated particle number concentration (PNC) and the mean diameter of a polydisperse aerosol.

In context of the mobile use of these hand-held systems we investigated their performance and reliability in comparative measurements. As a reference system we used a freshly from the manufacture calibrated SMPS, which yields good and comparable results to other SMPS systems from different manufactures, which are described in Kaminski et al., [9]. We compared the values from the reference system with the hand-held systems.

2 Methods

Several studies have been performed for comparative measurements under laboratory conditions between different SMPS systems as well as for hand-held systems [9–12].

In this study we compared two hand-held measurement devices (Testo DiSCMini and Grimm NanoCheck) with an SMPS (Grimm SMPS+C 5.420) under real environmental conditions of an urban area. Therefore, we integrated all three systems to the measurement truck of the laboratory for environmental measurement techniques and ran them in parallel over a whole week on the campus of the University of Applied Sciences in Duesseldorf, Germany. In the east, south and west boundary of the campus, there are streets with a traffic amount from about 8,000 (east), 24,000 (south) and 12,000 (west) vehicles per day [13]. To the north, there is a construction side, where a new building for another faculty is built. The inlet of all instruments were placed next to each other, one meter above the roof of the measurement truck, which is about four meter over ground.

3 Measurement Techniques

In this chapter the used measurement principles of the instruments are explained. An overview of the technical specifications are given in the following table (as stated by the manufacturers).

Table 1: Technical specification of the instruments

Device	SMPS+C	DiSCMini	NanoCheck
Size range [nm]	5 – 350	10 – 300	25 - 300
Concentration [#/cm³]	< 150.000	< 150.000	< 5x10^5
Time resolution [s]	240	1	10
Flowrate [lpm]	0.3	1	1.2
Accuracy	-	± 30 %	± 5 %

3.1 Scanning mobility particle sizer (SMPS+C)

The SMPS+C (Grimm Aerosol GmbH, type 5.420) is a combination of a differential mobility analyzer (DMA) and a condensation particle counter (CPC). Before the sample air is entering the DMA there is a two stage impactor, which has a cut off diameter (particle density ρ = 2.163 kg/cm³) from 707 nm, 350 nm respectively followed by an aerosol neutralizer. Instead of using a radioactive source for the aerosol neutralization this system uses a dielectric barrier discharger (a-DBD). The DMA (m-DMA, type Vienna) using high voltage to separate ultrafine particles with a specific size, which are counted afterwards with the CPC. With a known transfer function between voltage and particle mobility, described by Reischl et al., [14], the DMA is able to classify particles from 5.12 nm up to 350 nm in 44 channels. The CPC uses a heated saturator with an oversaturated butanol atmosphere and a cooled condensation chamber. First the particles pass the saturator, where they adsorb some butanol. After that they pass the condensation chamber where the butanol condensates and because of this, the particles grow up by size and can be detected. The CPC has a volume flow of 0.3 L/min and has a coincidence level up to 150,000 #/cm³. Depending on the range and number of channels the time resolution is up to 4 min for a single scan over the whole range with 44 channels.

Is it shown by Kaminski et al. [9] that the SMPS (Grimm SMPS+C 5.420), which is used for this study, can be regarded as a reference system. Within the investigations of Kaminski et al. several size distribution and size integrated measuring devices were investigated in parallel use. Therefore, unimodal test aerosols like NaCl (37 nm and 42 nm), DEHS (240 nm and 263 nm) and soot (59 nm, 100 nm and 106 nm) were generated in a windtunnel and measured by the instruments. Here all instruments showed a good comparability concerning the particle number concentration. Also the particle sizing was very good for the NaCl and soot aerosols. Only for the DEHS particles the SMPS+C (with short m-DMA) showed a less particle diameter.

3.2 Diffusion Charger Faraday Cup Electrometer

Both systems the DiSCMini (Diffusion Size Classifier) from Testo and the NanoCheck from Grimm use the same measurement principle. Both systems use an unipolar diffusion charger to charge particles followed by an electrometer stage. In a first step, air is led through a positive diffusion charger, where the particles adsorb a specific and size depending amount of charge [15]. Then they pass the diffusion stage and thereafter the filter stage. Particles captured in these stages generate a current. The ratio of these currents of the filter- and diffusion-stage are used for calculating the average particle size. A more detailed description is given by Fierz et al. [16].

The DiSCMini is really small (18 x 9 x 4 cm) and light weighted (0.7 kg), whereas the NanoCheck is only available as a combination of an optical particle counter (OPC) and a faraday cup aerosol electrometer (FCAE) downstream of the OPC. Because of this reason, the dimension from the NanoCheck are greater (38 x 12 x 29 cm) and heavier (8.2 kg) than the DiSCMini. Nevertheless, it is small and light enough for mobile use and indicates together with the OPC a broader size spectrum of the aerosol.

4 Results

Due to the different time resolution of the instruments, the data of each instrument were averaged about 10 min. In the following subchapters the results from the comparative measurements are shown. First for the particle number concentration and second for the average particle diameter.

4.1 Particle number concentration

The Fig. 1 shows the results of the measurements. In a) one can see the total particle number in #/cm³ for the three devices. The red line represents the data from the SMPS, the green line belongs to the NanoCheck and the blue line shows the data from the DiSCMini. The plots b) – d) are the regression analysis of the measured values.

In a) one can see that the dynamic of the concentration varies over a range from 500 #/cm³ up to 19,000 #/cm³ measured by the SMPS. One can clearly see, that all the three system show an equal trend. Furthermore, the PNC from the SMPS and the NanoCheck are in the same order. However, the PNC measured by the DiSCMini are higher than the PNC from the other both systems and are between 1,400 #/cm³ and up to 28,000 #/cm³.

The correlation plots underline these results. There is a good correlation between all of the instruments $R^2 > 0.72$. Also there is a well comparability between the SMPS and the NanoCheck. The DiscMini also correlates well, but shows higher PNC of a factor greater than two (Slope = 2.27 & 2.28).

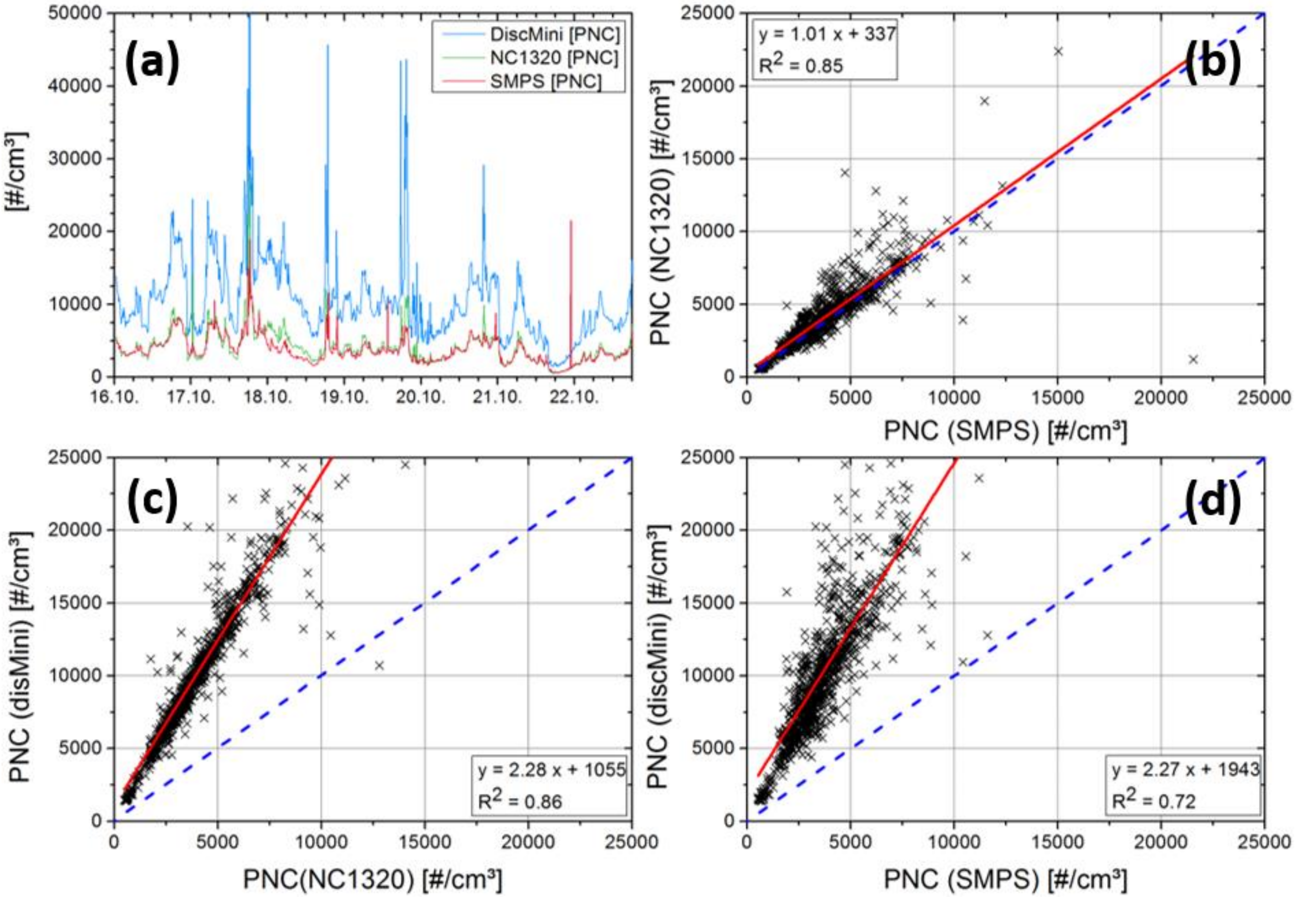

Fig. 1: a) Particle number concentration. b) correlation between SMPS and NC1.320. c) correlation between NC1.320 and DiSCMini. d) Correlation between SMPS and DiSCMini

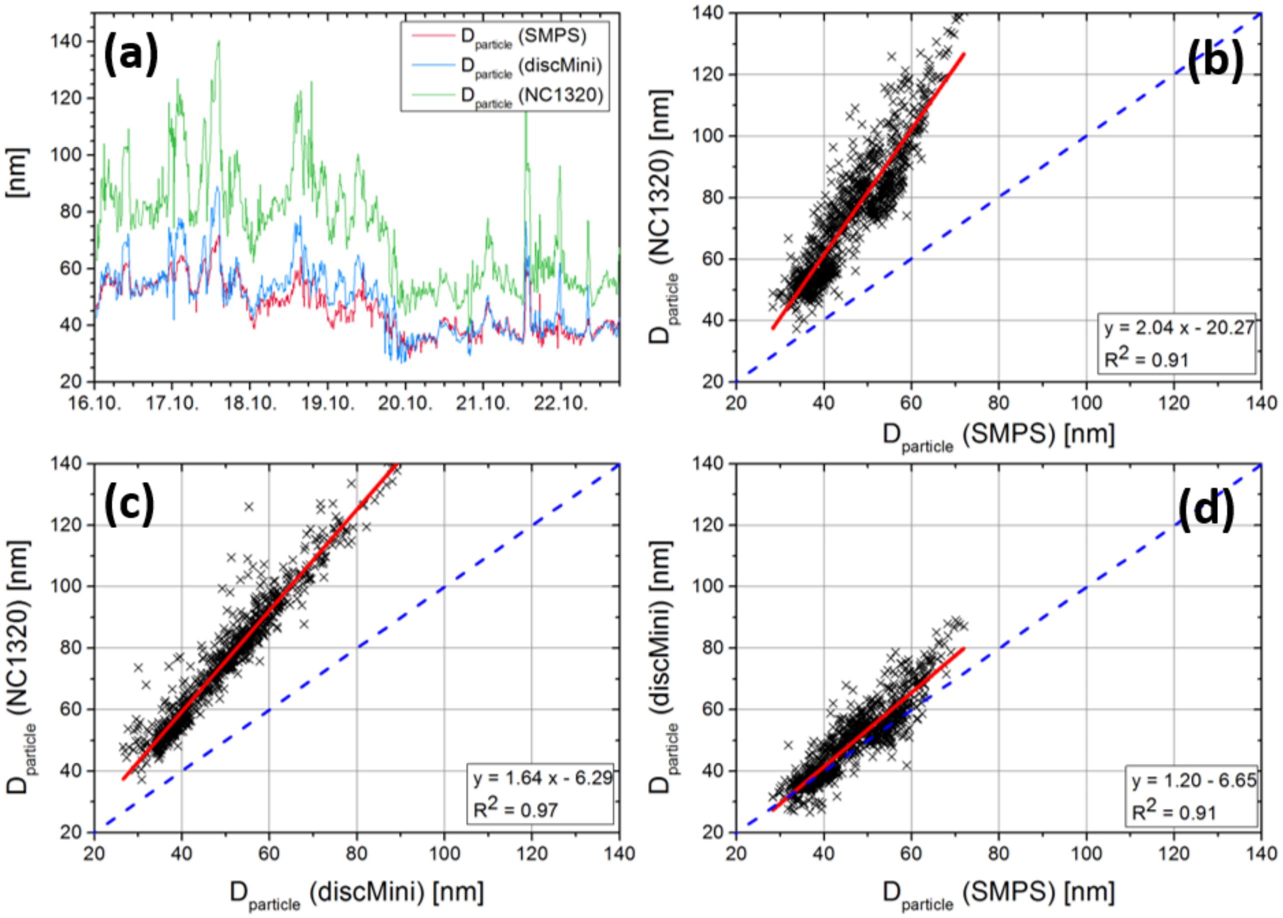

Fig. 2: a) Particle size in nm. b) correlation between SMPS and NC1.320. c) correlation between NC1.320 and DiSCMini. d) Correlation between SMPS and DiSCMini

4.2 Particle size

In the Fig. 2 the results of the measurements regarding to the average particle diameter are shown. The arrangement of the graphs is equal to the Fig. 1. In a) there is the average particle diameter over the time from all of the devices. In b) to d) the regression analysis is shown.

The particle diameters from the SMPS vary in a range from 28 nm up to 72 nm. All of the three devices show an equal trend. It can be said that the SMPS and the DiSCMini agree very well to each other, whereas the NanoCheck seems to overestimate the size of the particles, when used with measurement parameters set by the manufacturer. This can be seen also in the correlation plots. All R^2 values are greater than 0.9, which means that all three devices have a good correlation to each other. In contrast the comparability is not that good. The best size agreement is between the SMPS and the DiSCMini (slope = 1.20 and offset = -6.65), whereas the agreement between the SMPS and the NanoCheck (slope = 2.04, offset = -20.27) and between the DiSCMini and the NanoCheck (slope 1.64, offset – 6.29) is lower before post-processing.

4.3 Cross-calibration to fit the data

The results from the subchapter 4.1 for the particle number concentration show a good agreement between the data from the reference and the NanoCheck and an overestimation between the values from the DiSCMini and the SMPS without post-processing. Related to the good correlations of the regression analysis, it is possible to do a cross-

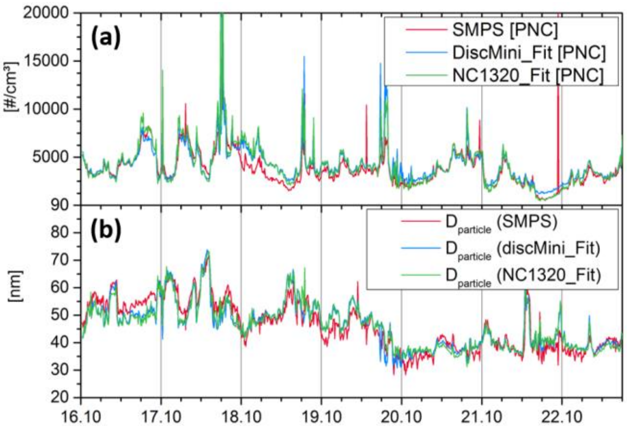

Fig. 3: Cross-calibrated data for PNC (a) and the particle size (b).

calibration of the data in a post-process. In Fig. 3 the fitted data from the DiSCMini and the NanoCheck together with the original data from the SMPS are shown for the particle number concentration (a) and for the particle size (b). It can be stated, that after that post-process, the data from both systems are in very good agreement with the reference.

5 Conclusion

The comparative study has shown, that hand-held devices like the DiSCMini and the Nanocheck are suitable for mobile measurements or the use as personal monitors. In comparison to the SMPS, which can be regarded as a reference system, these portable systems deliver reasonable results. These systems work well, not only under standardized conditions in the laboratory, but also under real environmental conditions.

The particle number concentration in the present work, measured by the SMPS under real environmental conditions was between 500 #/cm³ and 21,500 #/cm³. The data from the NanoCheck are in the same order and show a very good agreement, whereas the data from the DiSCMini had a good correlation, but a lower agreement.

However, it could be clearly demonstrated within this study that the data of the portable measurement systems NanoCheck and DiSCMini can be cross-correlated and re-calibrated by the SMPS as a reference system. With this post-processing all three systems show very good agreement in results. This is of high importance, because based on this outcome of the study the NanoCheck and DiSCMini can be used for various applications of mobile measurement of ultrafine particles using platforms like cars, bikes, unmanned aerial systems (UAS) and aircraft. This enables interesting new fields of research.

6 Acknowledgement

We gratefully thank the Deutsche Forschungsgemeinschaft DFG for the partly funding of the project. Moreover, the supply of data and the cooperation by the Environmental State Agency of North Rhine Westphalia LANUV NRW is greatly acknowledged.

References:

[1] Landrigan, P. J., Fuller, R., Acosta, N. J. R., Adeyi, O., Arnold, R., Basu, N., Baldé, A. B., Bertollini, R., Bose-O'Reilly, S. & Boufford, J. I. et al. 2017 The Lancet Commission on pollution and health. *The Lancet.*

[2] World Health Organization. 2016 *Ambient air pollution: A global assessment of exposure and burden of disease*. http://apps.who.int/iris/bitstream/10665/250141/1/9789241511353-eng.pdf?ua=1.

[3] André Nel. 2005 Air Pollution-Related Illness: Effects of Particles. *Science* No. 5723 (May 6, 2005), 804–806.

[4] Oberdörster, G., Sharp, Z., Atudorei, V., Elder, A., Gelein, R., Lunts, A., Kreyling, W. & Cox, C. 2002 Extrapulmonary translocation of ultrafine carbon particles following whole-body inhalation exposure of rats. *Journal of toxicology and environmental health. Part A* 65, 1531–1543.

[5] Wiedensohler, A., Birmili, W., Nowak, A., Sonntag, A., Weinhold, K., Merkel, M., Wehner, B., Tuch, T., Pfeifer, S. & Fiebig, M. *et al.* 2012 Mobility particle size spectrometers. Harmonization of technical standards and data structure to facilitate high quality long-term observations of atmospheric particle number size distributions. *Atmospheric Measurement Techniques* 5, 657–685.

[6] International Organization for Standatdization. 2009 Determination of particle size distribution — Differential electrical mobility analysis for aerosol particles, 1st edn.

[7] Bonn, B., Schneidemesser, E. von, Andrich, D., Quedenau, J., Gerwig, H., Lüdecke, A., Kura, J., Pietsch, A., Ehlers, C. & Klemp, D. *et al.* 2016 BAERLIN2014 – the influence of land surface types on and the horizontal heterogeneity of air pollutant levels in Berlin. *Atmospheric Chemistry and Physics* 16, 7785–7811.

[8] Weber, K., Heweling, G., Fischer, C. & Lange, M. 2017 The use of an octocopter UAV for the determination of air pollutants – a case study of the traffic induced pollution plume around a river bridge in Duesseldorf, Germany. *International Journal of Environmental Science*, 63–66.

[9] Kaminski, H., Kuhlbusch, T. A., Rath, S., Götz, U., Sprenger, M., Wels, D., Polloczek, J., Bachmann, V., Dziurowitz, N. & Kiesling, H.-J. *et al.* 2013 Comparability of mobility

particle sizers and diffusion chargers. *Journal of Aerosol Science* 57, 156–178.

[10] Asbach, C., Kaminski, H., Barany, D. von, Kuhlbusch, T. A. J., Monz, C., Vossen, K., Perlzer, J., Berlin, K., Dietrich, K. & Götz, U. *et al.* 2012 Comparability of Portable Nanoparticle Exposure Monitors. *Annals of Occupational Hygiene (Ann. Occup. Hyg.)*, 606–621.

[11] Asbach, C., Kaminski, H., Fissan, H., Monz, C., Dahmann, D., Mülhopt, S., Paur, H. R., Kiesling, H. J., Herrmann, F. & Voetz, M. *et al.* 2009 Comparison of four mobility particle sizers with different time resolution for stationary exposure measurements. *Journal of Nanoparticle Research* 11, 1593–1609.

[12] Bau, S., Zimmermann, B., Payet, R. & Witschger, O. 2015 A laboratory study of the performance of the handheld diffusion size classifier (DiSCmini) for various aerosols in the 15-400 nm range. *Environmental science. Processes & impacts* 17, 261–269.

[13] Amt für Verkehrsmanagement. 2015 *Verkehrsbelastung:* Landeshauptstadt Düsseldorf.

[14] Reischl G.P. 1991 The Relationship of Input and Output Aerosol Characteristics for an ideal Differential Mobility Analyser Particle Standard. *Journal of Aerosol Science*, 297–312.

[15] Jung, H. & Kittelson, D. B. 2007 Characterization of Aerosol Surface Instruments in Transition Regime. *Aerosol Science and Technology* 39, 902–911.

[16] Fierz, M., Houle, C., Steigmeier, P. & Burtscher, H. 2011 Design, Calibration, and Field Performance of a Miniature Diffusion Size Classifier. *Aerosol Science and Technology* 45, 1–10.