Analysis of the Optec NGN-3 $PM_{2.5}$ Size-cut Nephelome

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ABSTRACT

The Optec NGN-3 nephelometer measures continuous $PM_{2.5}$ aerosol scattering and can be used as a surrogate for $PM_{2.5}$ mass. The Optec NGN-3 is based on the Optec NGN-2 ambient nephelometer, which has operated successfully since its introduction in 1993 as part of the IMPROVE program, other national and state visibility programs, and high-profile special studies.

Based on its success and acceptance in the visibility monitoring community, and the need for a surrogate for continuous $PM_{2.5}$ mass measurement in urban areas, the NGN-2 has been modified and configured with a 2.5 µm size-cut device and an inline sample heater to measure the dry scattering of fine mass. This modified nephelometer, the NGN-3, integrates the original optical design, a well-characterized size-cut inlet, a critical orifice designed for 7 LPM, an inline heater, and a long-life pump. The size-cut configuration was tested against a variety of aerosol samplers and monitors in Bakersfield, California during Winter 1999, and against an IMPROVE stage A aerosol sampler in Fort Collins, Colorado during Spring 1999. The results of those studies and an analysis of the Optec size-cut nephelometer as a surrogate for $PM_{2.5}$ mass measurement are presented.

INTRODUCTION

Measuring the mass of airborne particulates is critical to local, state, and national air quality monitoring programs. In the past, aerosol mass measurements have primarily been performed with filter-based sampling devices and laboratory analyses of collected filters. While filter-based sampling and analysis still plays an important and unique role in air quality monitoring there has been growing interest in the development of a scattering-based surrogate for real-time continuous $PM_{2.5}$ mass measurements.

OPTEC NGN-3 SIZE-CUT NEPHELOMETER

The new Optec NGN-3 size-cut and heated nephelometer was specifically designed as a surrogate for $PM_{2.5}$ sampling. The NGN-3 integrates the optical design of the original NGN-2 ambient nephelometer[1,2] with a 2.5 µm size-cut device and an inline sample heater to measure the dry scattering of fine mass. To ensure monitoring accuracy, the instrument performs automatic zero calibrations at user-defined intervals and allows for manual zero and upscale calibration checks at any time. Once measured, the particle scattering is converted to mass using a region-specific, user-selected empirical conversion factor. The NGN-3 continuously outputs both a particle scattering and a fine mass measurement with a minimum integration time of 2 minutes.

Unlike its predecessor, the NGN-3 operates indoors and draws ambient air through a sample inlet line. An SKC Spiral Inlet mounted at the sample air inlet removes coarse particulates from the sample stream. As shown in the cut point vs. flow curve presented in Figure 1, a flow rate of 7 LPM is required to achieve a size-cut of 2.5 µm.[3] The sample flow rate in the nephelometer is determined by a fixed critical orifice downstream of the optical chamber. The SKC Spiral Inlet is small and easily opened for inspection and cleaning. The sample air is heated (to lower its humidity) upon entering the nephelometer and the elevated sample air temperature is continuously logged.

The NGN-3 relies on the same high-quality optics, stable solid-state electronics, and both analog and serial (RS232) outputs as the NGN-2. Additions to the system include an integrated numeric output display, and external switching to select the desired parameters to display and to initiate manual calibrations.

INITIAL TESTS OF THE NGN-3

The California Air Resources Board hosted a comparison study of continuous sampling instruments in Bakersfield, California, during Winter 1999. An NGN-2 ambient nephelometer and an NGN-3 size-cut nephelometer operated throughout the study. Hourly average fine mass values in the range 0.6 to 165 $\mu g/m^3$ were measured by the NGN-3 during the Bakersfield study.

Scattering data from the ambient nephelometer was filtered for weather effects by flagging all data collected when the relative humidity was greater than 90%.[2] A complete timeline of the non-weather affected hourly Bakersfield NGN-2 and NGN-3 particle scattering data is presented in Figure 2. The magnitude of the NGN-3 data trace can be interpreted with either the particle scattering axis on the left or the fine mass axis on the right. The conversion used between particle scattering and fine mass for the Bakersfield study was:

$$\text{Fine Mass Concentration} = \text{Particle Scattering} / 3.00$$

This user-defined conversion factor will vary by region and is stored in the instrument's memory. The two nephelometers agreed well when the RH was low and separated as the RH increased. Even when the RH was high both nephelometers simultaneously tracked short-term events.

It is to be expected that the particle scattering measured by the ambient NGN-2 should always be greater than the particle scattering measured by the NGN-3 because the size-cut and heated NGN-3 nephelometer sees only a subset of the aerosols seen by ambient nephelometer. This difference is related in large part to the ambient relative humidity (RH), and in smaller part to the absence of coarse particles in the NGN-3's sample stream. Figure 3 presents scatter plots of particle scattering measured by the ambient and size-cut nephelometers under the conditions of RH<50%, RH<70%, and RH<90%.

Further comparisons between the NGN-3 and other mass measurement instruments are expected to be released later this year.

ACCURACY AND PRECISION TESTS OF THE NGN-3

Two NGN-3 nephelometers and one IMPROVE stage A aerosol sampler with a $PM_{2.5}$ inlet were operated side by side during Spring 1999, in Fort Collins, Colorado. Continuous 2-minute data were collected with the nephelometers. Daily 24-hour filter samples (noon to noon) were collected with the aerosol sampler.

Analysis of the sample filters yielded 24-hour fine mass concentrations which were then compared to the same 24-hour average fine mass output from both NGN-3 nephelometers. The user-defined conversion between particle scattering and fine mass was set to 3.0. A scatter plot of all data is presented in Figure 4. The best fit line shown on the graph is based on all data except the two outlying points noted. The NGN-3 nephelometers agreed well with the filter-based fine mass concentrations ($r^2 = 0.81$), and underestimated filter-based fine mass measurements on average by 1.34 $\mu g/m^3$.

The NGN-3 testing in Fort Collins was conducted in two stages. From March 4 to 23, 1999, both nephelometers were identically configured. A scatter plot of the hourly average particle scattering (b_{sp}) is presented as Figure 5. A histogram of the hourly differences between the nephelometers is shown in Figure 6. The mean of the differences was 0.56 Mm^{-1} (0.19 $\mu g/m^3$) with a standard deviation of 1.23 Mm^{-1} (0.41 $\mu g/m^3$).

From March 23 to April 9, 1999, one of the size-cut inlets was lightly greased (following the manufacturer's suggestion) with Apiezon-M grease to investigate whether some coarse particles were penetrating the inlet.[3] A scatter plot of the hourly average nephelometer data from this period is presented as Figure 7. A histogram of the hourly differences between the NGN-3 nephelometers is shown in Figure 8. Greasing the size-cut inlet changed the mean hourly difference between the nephelometer measurements to –1.71 Mm^{-1} (-0.57 $\mu g/m^3$), meaning that the nephelometer with the greased inlet, on average, measured a slightly lower particle scattering. The standard deviation of the differences was 2.34 Mm^{-1} (0.78 $\mu g/m^3$). It is important to note that when the inlets were ungreased the nephelometers experienced occasional spikes (high 2-minute readings) on very windy days. These spikes were significantly diminished when the nephelometer was operated with a greased inlet, indicating that the spikes could have been caused by the intrusion of coarse particles suspended by strong winds.

CONCLUSIONS

The NGN-3 nephelometer was operated alongside an NGN-2 ambient nephelometer in Bakersfield, California, during Winter 1999. Both instruments tracked short-term visibility episodes well, especially at low ambient relative humidities.

Two NGN-3 nephelometers were tested against an IMPROVE stage A aerosol sampler with a $PM_{2.5}$ inlet in Fort Collins, Colorado, during Spring 1999. With two outlying data points removed, test results showed a strong correlation ($r^2 = 0.81$) between 24-hour average nephelometer fine mass and filter fine mass measurements, with an average underestimate of fine mass by the nephelometer of 1.34 $\mu g/m^3$.

Precision calculations between the two NGN-3 nephelometers showed the average difference between the paired hourly measurements to be 0.56 Mm^{-1} (particle scattering) or 0.19 $\mu g/m^3$ (fine mass) with a standard deviation of 1.23 Mm^{-1} (particle scattering) or 0.41 $\mu g/m^3$ (fine mass).

Additional tests indicated that the SKC Spiral Inlet which provides the necessary 2.5 μm size-cut may on occasion, allow the penetration of some coarse particles. Lightly greasing the inlet with Apiezon-M grease appeared to eliminate this problem.

The new Optec NGN-3 size-cut and heated nephelometer effectively measures dry scattering of fine mass. It tracks well with the NGN-2 ambient nephelometer under a wide range of pollution conditions and is not affected by ambient humidity. The NGN-3 is a satisfactory surrogate for $PM_{2.5}$ mass measurements, and additionally yields real-time, continuous particle scattering and $PM_{2.5}$ measurements.

REFERENCES

1. Molenar, J.V.; Cismoski, D.S.; Tree, R.M. "Intercomparison of Ambient Optical Monitoring Techniques", in *Proceedings of 85th Annual Meeting &Exhibition Kansas City, Missouri, June 21 – 26, 1992*, Air & Waste Management Association: Pittsburgh, 1992; Paper 92-60.09.

2. Molenar, J.V. "Analysis of the Real World Performance of the Optec NGN-2 Ambient Nephelometer", in *Proceedings of a Specialty Conference Sponsored by the Air & Waste Management Association and the American Geophisical Union, September 9 – 12, 1997, Bartlett, NH*, Air & Waste Management Association: Pittsburgh, 1997; pages 243 – 265.

3. Hering, S.; Kreisberg, N; personal communication.

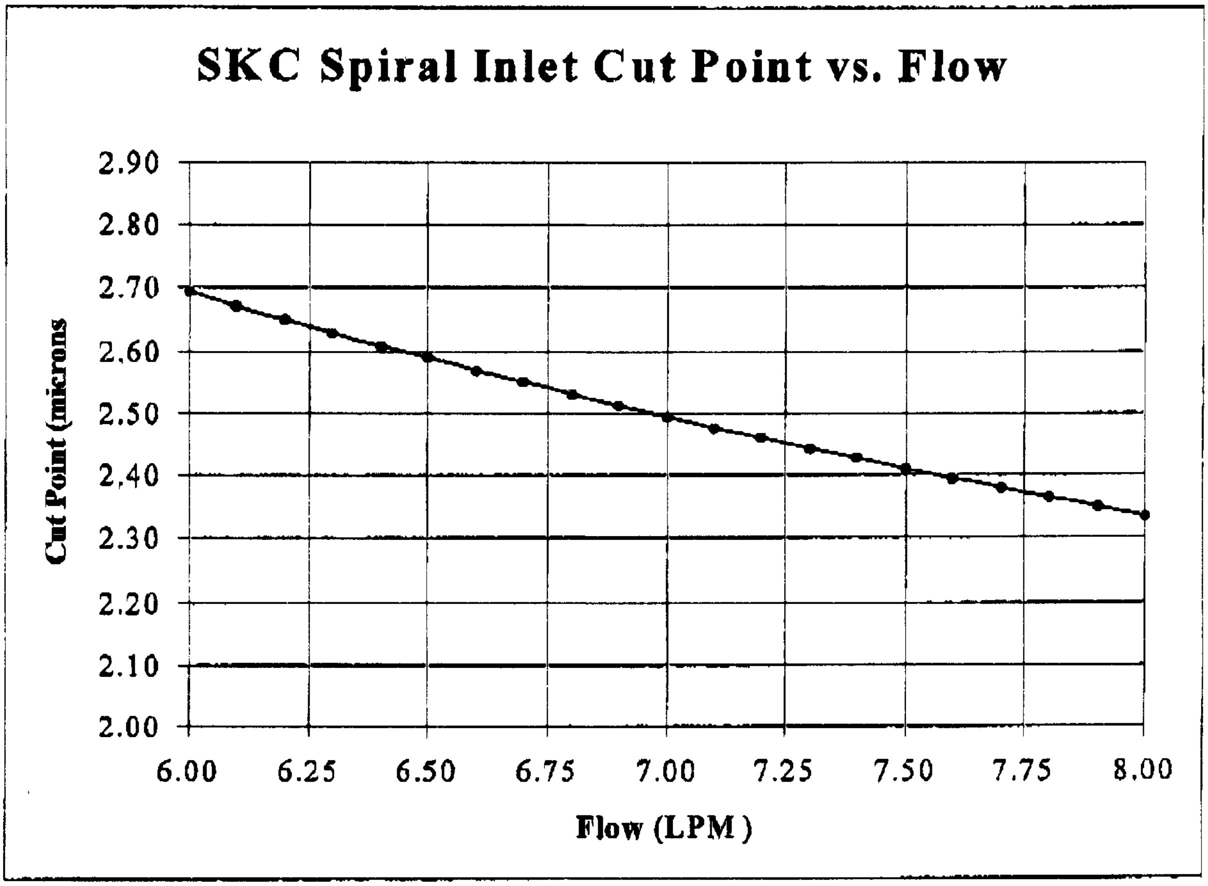

Figure 1. Cut Point vs. Flow curve for the SKC Spiral Inlet used in the NGN-3 nephelometer.

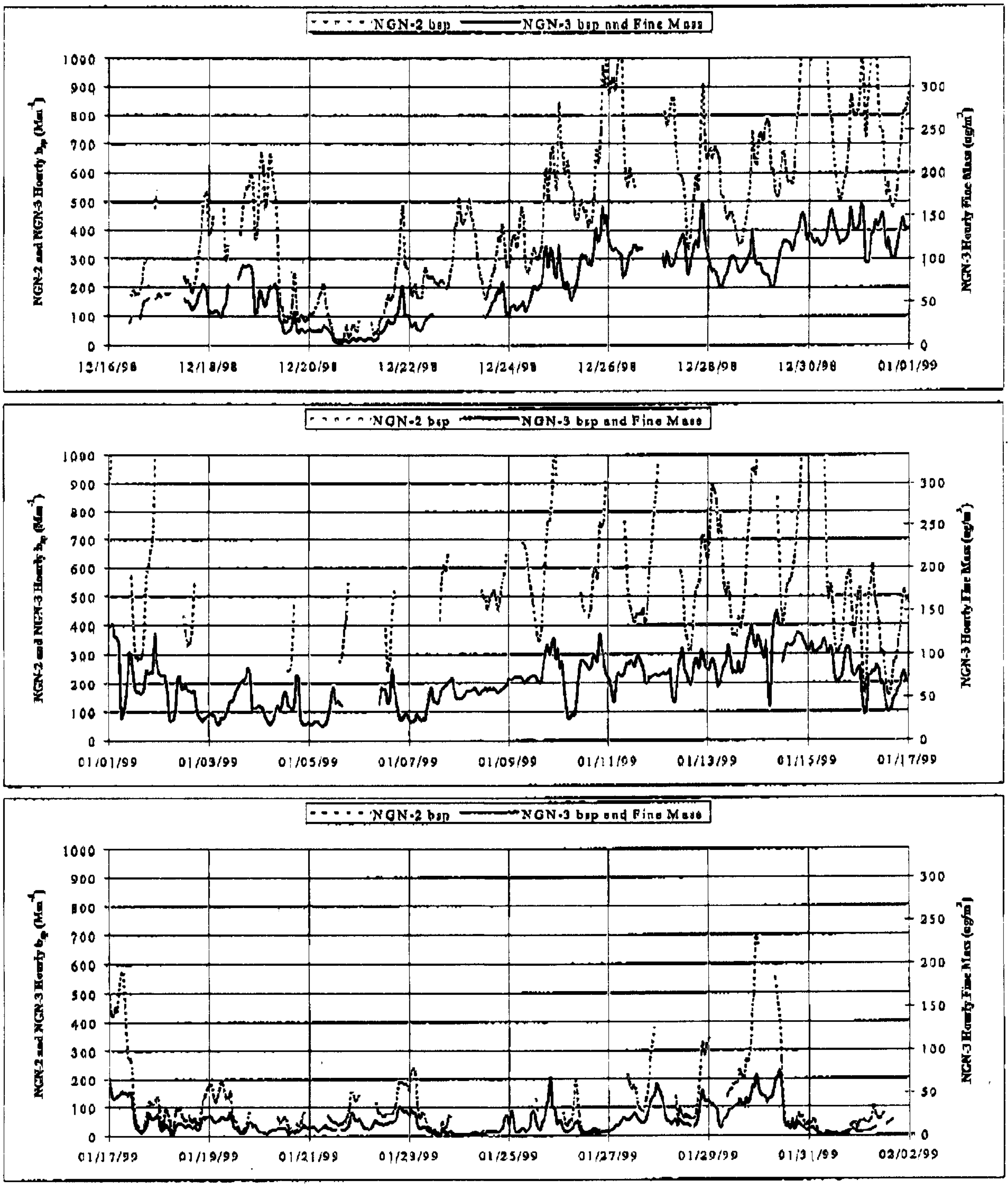

Figure 2. Complete timeline of hourly average non-weather affected (RH < 90%) NGN-2 and NGN-3 particle scattering (b_{sp} in Mm^{-1}) and fine mass (in $\mu g/m^3$) measurements collected in Bakersfield, CA.

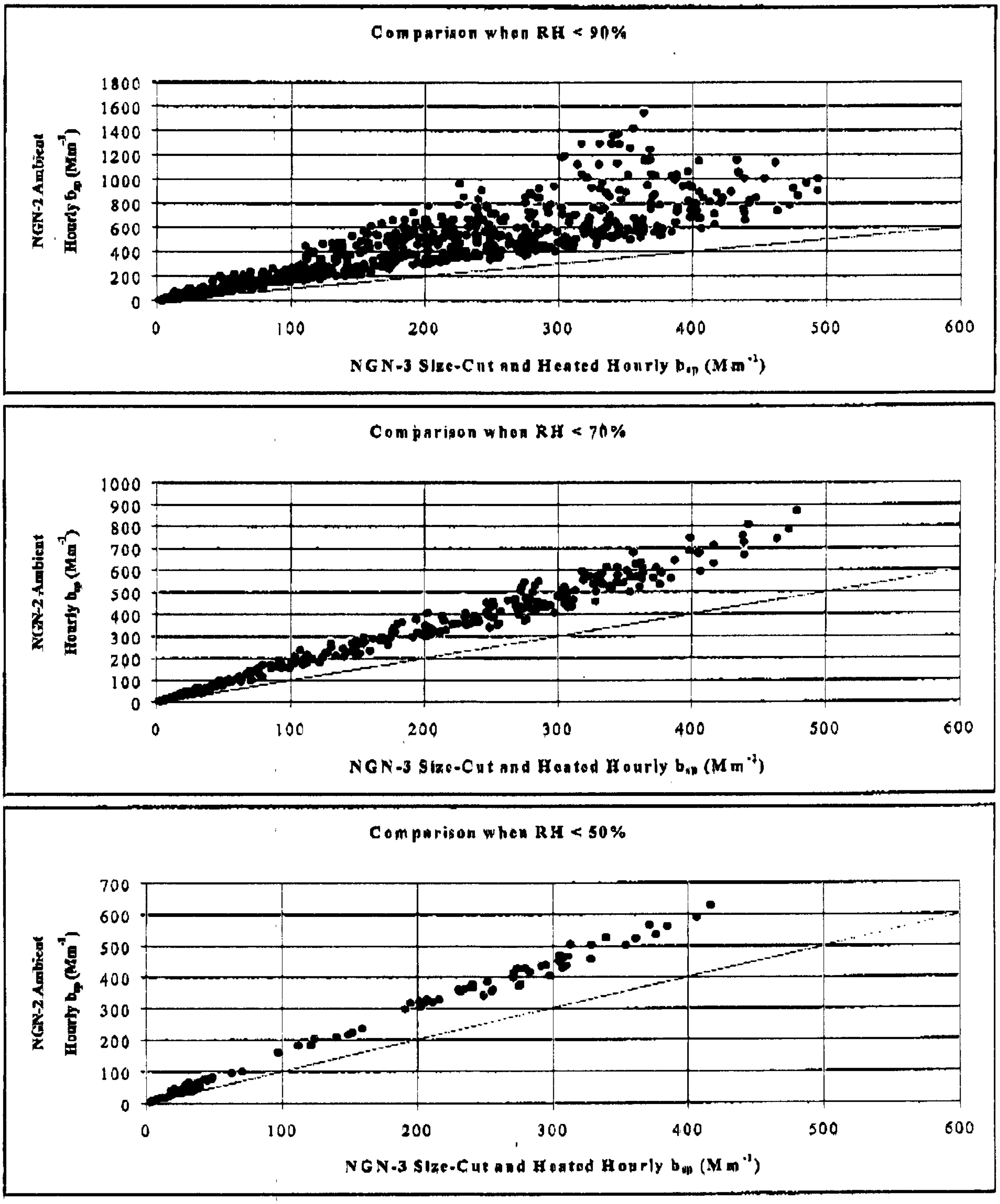

Figure 3. Scatter plots of hourly NGN-2 and NGN-3 particle scattering measurements collected in Bakersfield, CA, when RH is less than 90%, 70%, and 50%. The one-to-one line is shown.

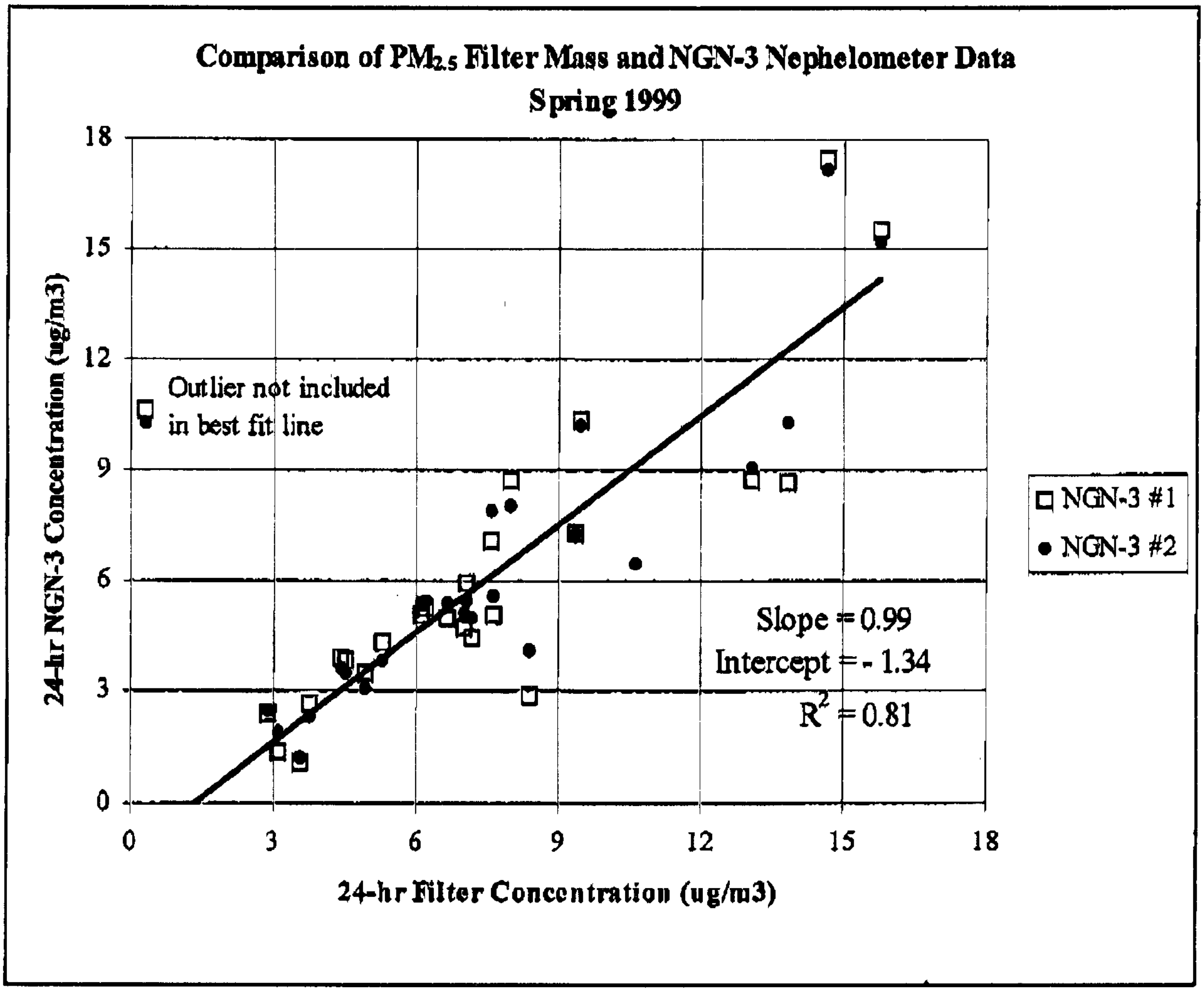

Figure 4. Comparison of $PM_{2.5}$ filter mass and NGN-3 measured mass collected in Fort Collins, CO. The best fit line does not include the two outlying data points noted on the graph.

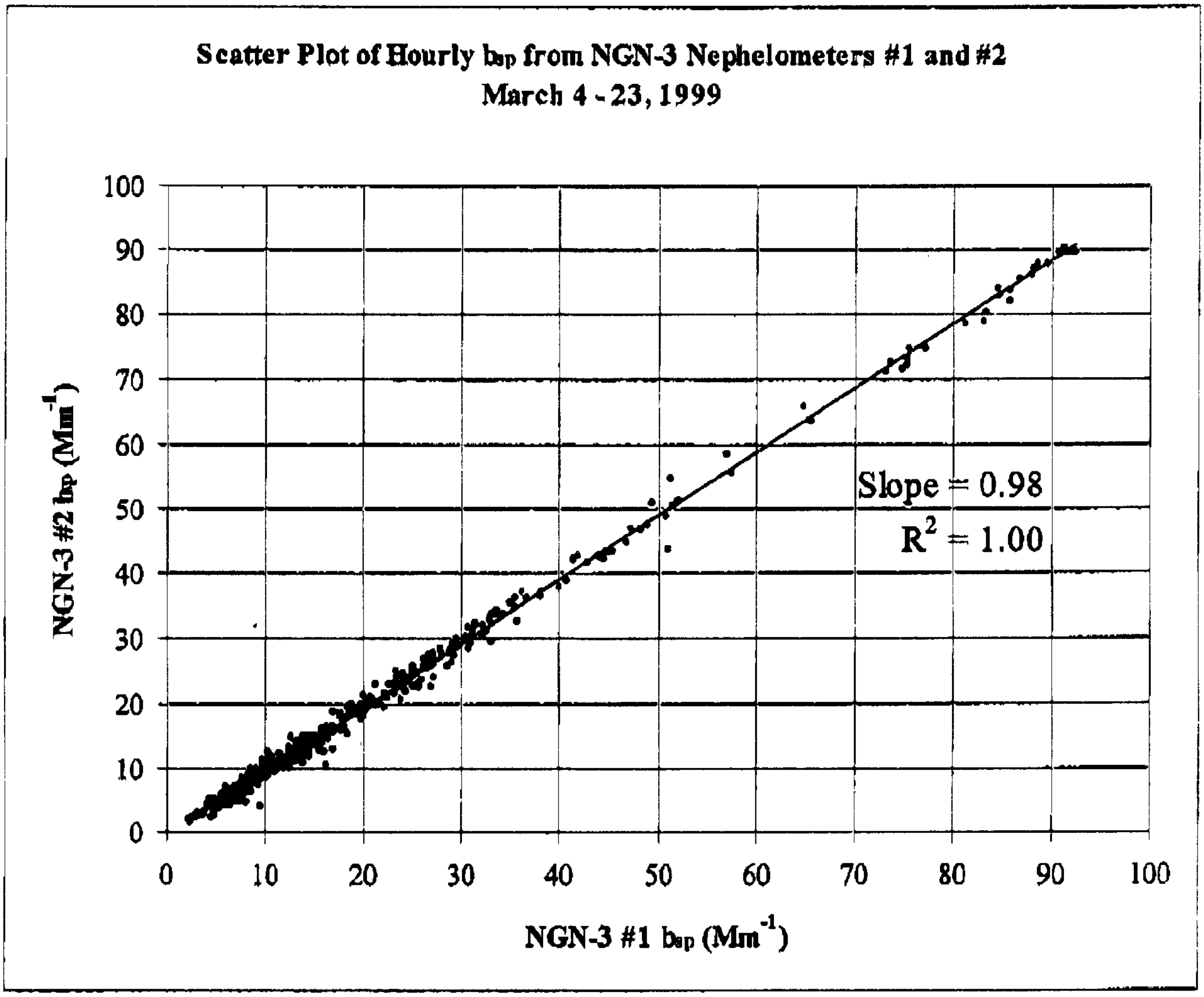

Figure 5. Scatter plot of NGN-3 hourly particle scattering measurements collected in Fort Collins, CO, when both nephelometers were configured identically.

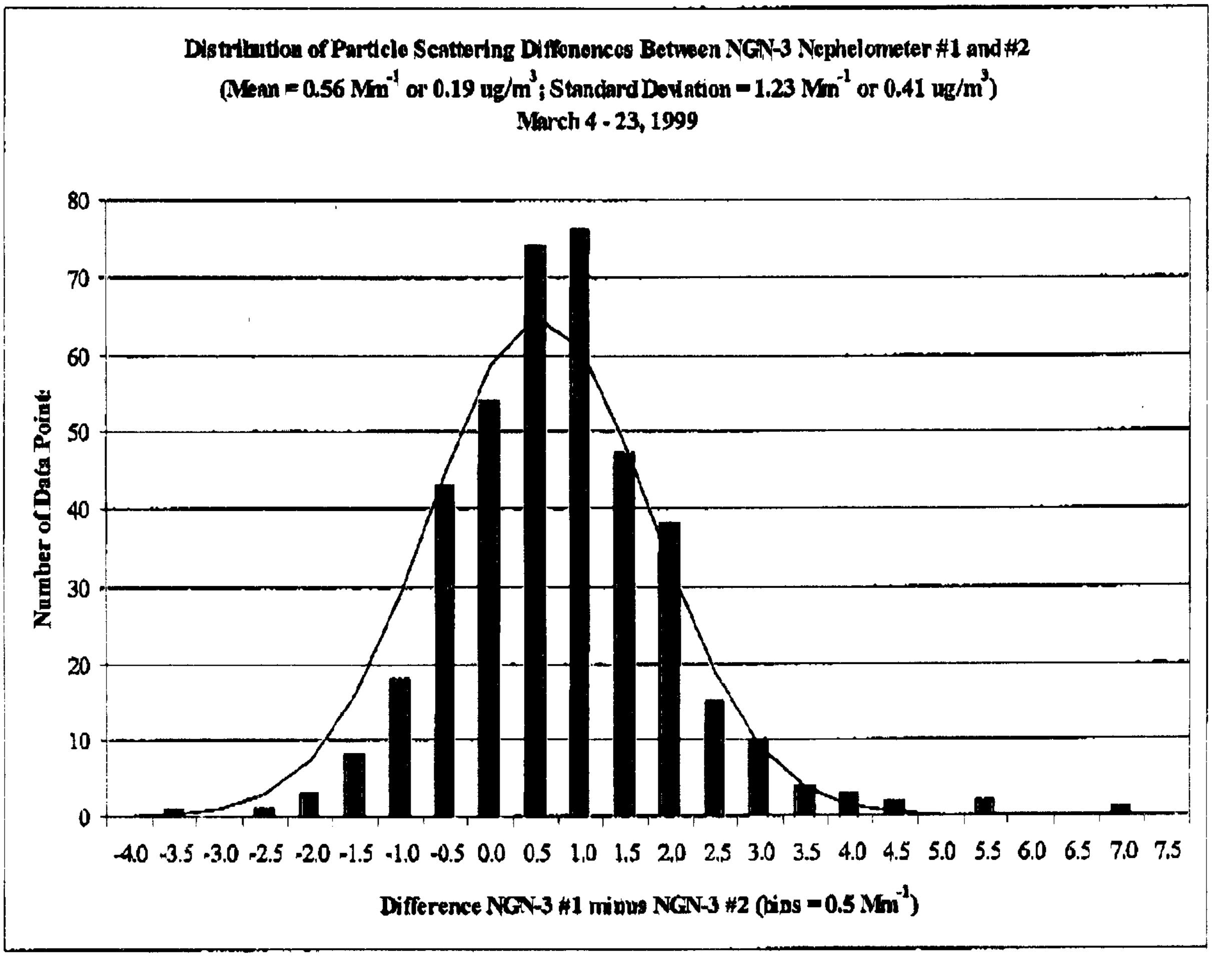

Figure 6. Histogram showing the distribution of differences between hourly average NGN-3 #1 and #2 particle scattering measurements collected in Fort Collins, CO, when both nephelometers were configured identically.

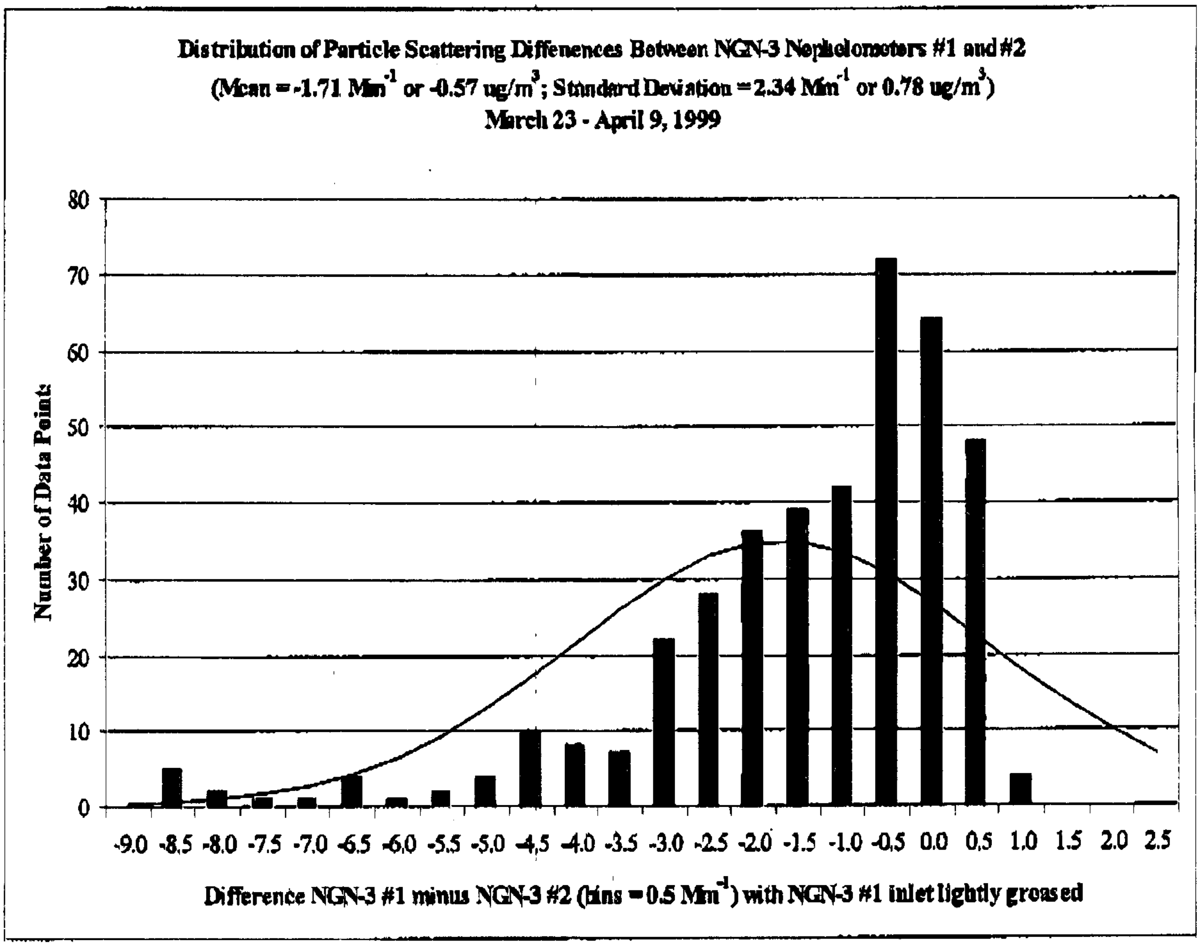

Figure 8. Histogram showing the distribution of differences between hourly average NGN-3 #1 and #2 particle scattering measurements collected in Fort Collins, CO, when the NGN-3 #1 size-cut inlet was lightly greased with Apiezon-M grease and the NGN-3 #2 size-cut inlet was left ungreased.