Use of a multi wavelength integrating Nephelometer to determine particle concentration and size

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Introduction
The US-EPA has emphasized the importance of measuring pollutant concentrations near highly traveled roads. Measuring particle concentration and other properties is an important step in finding answers as to how traffic contributes to the pollutant mix in a given area. Setting up instruments in these locations is not always easy. Occasionally there are shelters available near the roads to be measured. The picture below shows a typical setup next to I-40 in Raleigh, NC.

The Aurora 3000 Nephelometer is set up outside the main container in a weatherproof housing. The upper part of the housing contains the Nephelometer and the lower part acts as a stand and contains the CO₂ cylinder used to calibrate and remotely check the instrument.

Aurora 3000 – 3 wavelength Integrating Nephelometer
The key components of the Aurora 3000 are a 3 wavelength LED light source, a photomultiplier (PMT) and a reference shutter module to create a zero and reference light. A light trap prevents reflection of scattered light back to the PMT. Barometric pressure and air temperature are also measured.

Scattering Ångström Exponent
The Ångström Exponent (Å) expresses the spectral dependence of aerosol optical depth (σ) on scattering coefficient, absorption coefficient, etc.), with the wavelength of light (λ) as inverse power law:

\[ \sigma (\lambda) \sim \lambda^{-\text{Å}}. \]

The Ångström exponent is inversely related to the average size of aerosol particles: the smaller the particles, the larger the exponent. The exponent can be obtained from a two wavelength measurement of \( \sigma_{\text{scat}} \) by following relationship:

\[ \text{Å} = \frac{\ln(\sigma_{\lambda_2}) - \ln(\sigma_{\lambda_1})}{\ln(\lambda_2) - \ln(\lambda_1)} \]

Generating Size specific information with Scattering Ångström Exponent

Here the red scattering coefficient is shown vs. the Ångström coefficient. Generally some diurnal trends can be seen. During daytime particle sizes are bigger and concentrations increase. In the lower expanded section short term changes of particle sizes and their contribution to the scattering coefficient can be identified. The errors of this method are within the low noise band and show the methods high precision.

Lower Scattering Ångstrom Exponent – bigger particles
Daily averages for the SAE vs PM₂.₅ fraction show that a shift of average particle diameter towards higher diameters causes the average Ångström exponent to drop. Ångström Exponents > 1.9 are mainly PM₁₀ and smaller.

Scattering Ångstrom Exponent – for source apportionment
Direction of higher concentration and low Ångström numbers are the same indicating bigger (coarse) particles coming from there. The aerial view reveals a construction site very close by, where construction work was likely being performed causing a dust cloud to impact the station. Concentration levels from other directions and their respective Ångström exponents can give estimation of the influence from the construction site to the total daily measurement. This influence can then be deducted from roadside studies if needed.

Influence of Humidity

“Dry-Mode” with new “Naphion” Dryer
To avoid losses of volatile particles

The Nephelometer at the Tumbler Ridge site is not operated in the visibility mode but with an internal heater RH setting of <40%, significantly limiting the influence of RH on the calibration factor as shown on the left.

Conclusions

Integrating Nephelometers are a valuable tool to study short term changes in aerosol concentrations. The use of the Ångström factor method gives another dimension to the measurement as changes in particulate size distributions within the PM concentrations can be seen. The use of multi wavelength instruments are key for this approach. The accuracy of the Aurora 3000 is typically 0.3nm⁻¹ for a 1 minute average this would translate to about 0.056 µm²g⁻¹.

The Ångström Exponent method allows for an identification of aerosol signatures outside the regular site mix and can help to estimate the influence of irregular events (e.g., scattering information can help to identify biomass burning effects, as the organic carbon content is usually high).

Acknowledgments
Sue Kimbrough and Richard Snow, US-EPA Office of Research and Development
Ken Buckley, Georgia DNR

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Nephelometers measure predominantly fine particulates. The following Graph shows a comparison with a FEM-BAM-1020 PM₂.₅ System at a rural site near Tumbler Ridge, BC, Canada. The PM₂.₅ hourly concentration is compared to the “green” scattering coefficient scaled by an average factor of 5.2. The data points with the error bars show the actual hourly “calibration” factor, by dividing \( \sigma_{\text{scat}} / \text{FEM-PM}_2.5 \)

Note: The shown error bars was all based on a σ=2.5µg/m³ BAM value. The influence of this error can be seen in the picture left where the 2 sigma limits have been calculated and with the actual data compared.