Development of a Portable Atmospheric Particulate Extinctiometer (APEx) Based on Direct Absorbance in the Visible and Near IR

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Abstract: A portable particle extinctiometer based on direct absorbance at visible and near IR wavelengths is under development. The instrument is a derivative of the Model 405 NO_2/NO/NO_x Monitor recently introduced by 2B Technologies, which measures NO_2 by direct absorbance at 405 nm using a ~2 m path length, LED light source and photodiode detector. The long path length is achieved by use of either a miniature White cell (original Model 405) or by use of a tubular folded path using corner cube mirrors (new version of Model 405). An advantage of the tubular folded path is a much smaller flush volume, allowing measurements every 5 s. For particle extinction measurements, the NO_2 scrubber is simply replaced with a particle filter. Both approaches to achieving a long path length are being evaluated for measurements of total aerosol particle extinction (absorbance plus scattering). Preliminary experiments show good correlation with a Cavity Attenuated Phase Shift (CAPS) instrument for laboratory-generated aerosols, and a roadside monitoring experiment shows good correlation of measured particle extinction with PM2.5. The ultimate goal of the project is to provide a lower cost, lower power and more portable alternative to CAPS for measurements of particle extinction, B_{ext}. When used in combination with a miniature integrating nephelometer to measure the scattering coefficient, B_{scat}, it will be possible to obtain particle absorbance, B_{abs}, at multiple wavelengths by difference, $B_{abs} = B_{ext} - B_{scat}$.

1. Introduction

- Optical methods are commonly used for measuring concentration, radiative properties, and size distributions of aerosols. All are key to understanding aerosol effects on health and climate.
- Light extinction (B_{ext}) of aerosols is key to understanding atmospheric radiation balance. B_{ext} is due to two processes: absorption (B_{abs}) and scattering (B_{scat}): $B_{ext} = B_{abs} + B_{scat}$.
- B_{abs} is typically related to the content of black carbon (BC) in aerosols. BC has been shown to have serious impacts on human health (EPA, https://www.epa.gov/air-research/black-carbon-research).

- Currently, most methods for measuring aerosol absorption rely on collecting particulates on filters which are adversely affected by multiple scattering and reflections within the filter matrix (Coen et al., *Atm. Meas. Tech.*, 2010, 3, 457).
- Direct aerosol absorption or extinction methods such as Cavity Attenuation Phase Shift Spectroscopy (CAPS) or photoacoustic techniques are expensive and require significant power and/or expertise to operate.

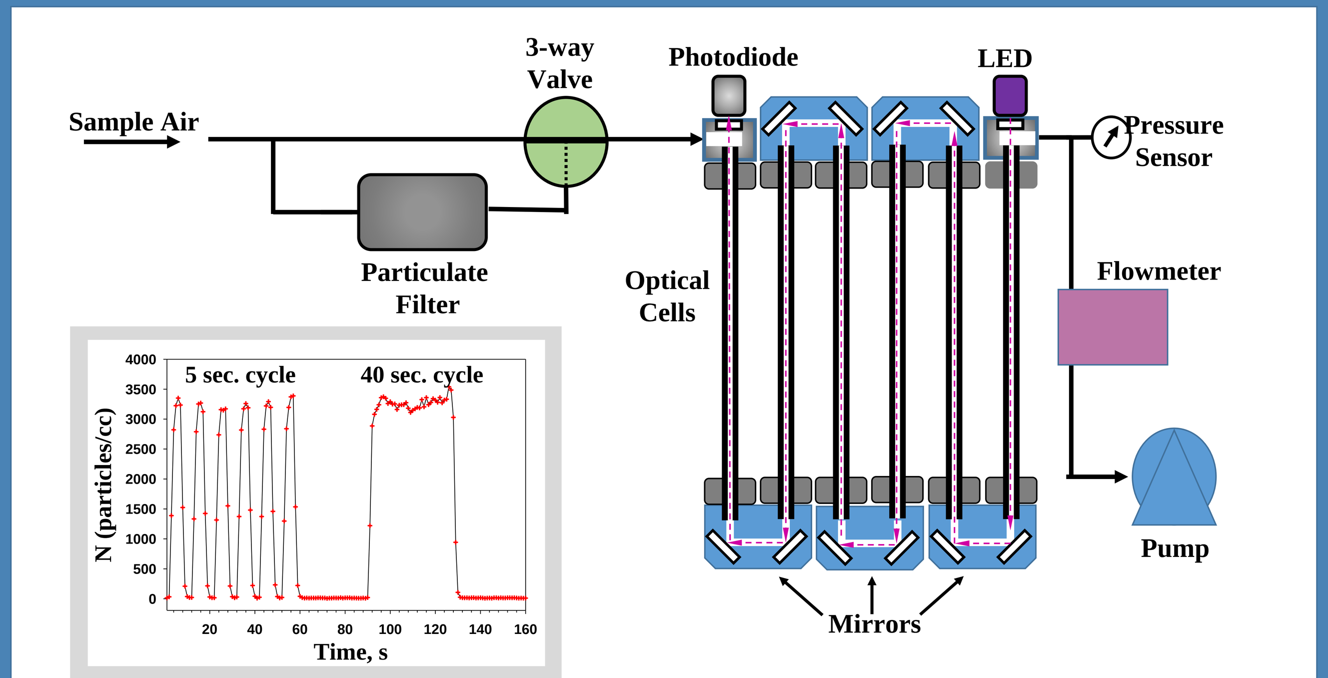
- ***There is a need for a relatively inexpensive, simple, robust analyzer to measure optical extinction and absorption from atmospheric aerosols without the use of filter collection.***
- ***We present results from a prototype long path photometer for aerosol extinction from a collaboration between 2B Technologies and Los Alamos National Lab.***

2. Goals

Phase 1: Produce a long path photometer to measure total light extinction from aerosols that will give results comparable to existing technologies and be:
- Easy to operate
- Robust and portable
- Low power
- Inexpensive (< $10K)

Phase 2:
1. Measure at multiple wavelengths across the UV to near-IR spectrum.
2. Incorporate an integrating sphere nephelometer to measure B_{scat} independently (and subsequently obtain B_{abs} by difference).

3. Initial Prototype



Atmospheric Particulate Extinctiometer (APEx)

Based on our existing 2B Technologies Model 405 for NO_2

- Basic absorption photometer. Intensity measured with (I) and without (I_o) particulate filter. Extinction is then: $B_{ext} = \frac{1}{L}\ln\left[\frac{I_o}{I}\right]$
- Inset above demonstrates sampling cycle with NaCl aerosols measured at the exit of the optical cells using a CPC (TSI, Model 3007).
- Long folded path required for necessary precision: Path length (L) = 2.1 m. At 1 Lpm: τ_{flush} ~ 2.2 sec.
- Rapid comparisons to reference (I_o) enhances precision for a given path length and minimizes offset drift due to contamination of mirrors or windows.
- LED light source at 405 nm (blue) or 780 nm (near IR).
- Teflon filter removes aerosols but passes gas phase absorbing species (e.g., NO_2) – thus canceling out in I and I_o.

4. Initial APEx Prototype Specifications

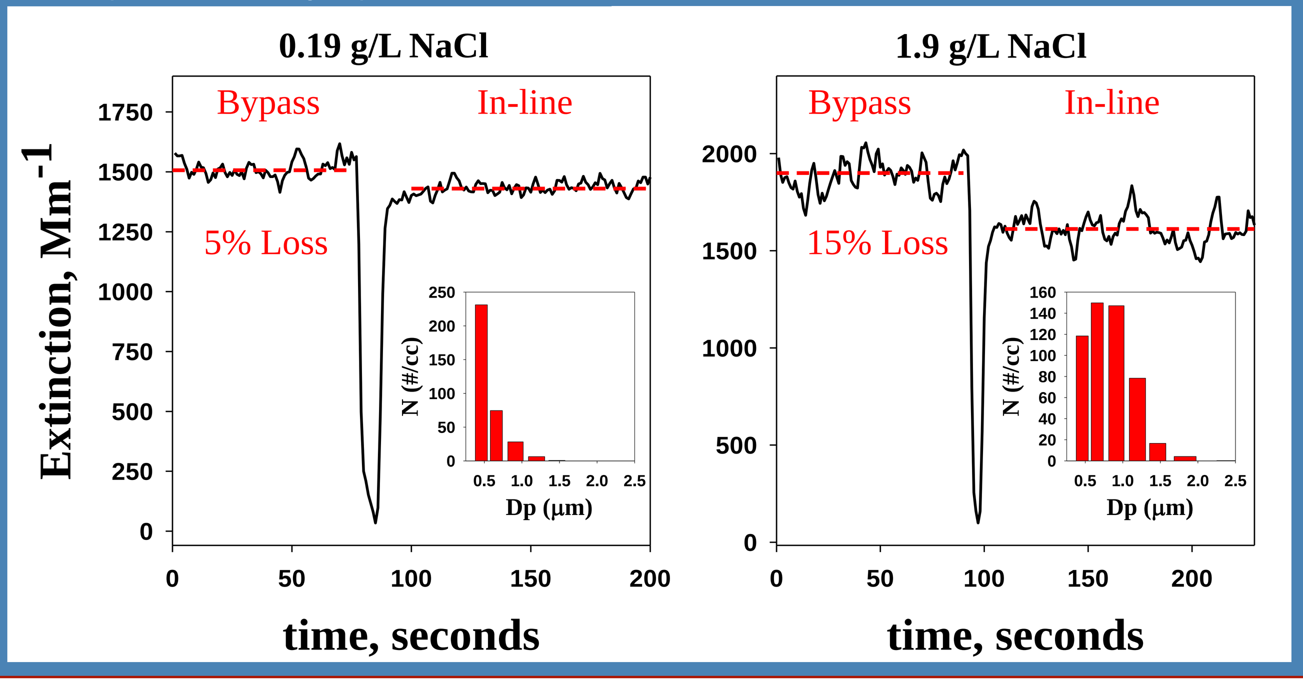
Materials Exposed	Stainless Steel, Conductive Silicon, Aluminum
Flow Rate	1.0 to 1.3 Liter/min
Sample Frequency	0.2 Hz (5 s)
Zero Precision (1σ)	405 nm: 3.9 Mm^{-1}; 1.0 Mm^{-1} (with adaptive filter)[1] 780 nm: 2.5 Mm^{-1}; 0.63 Mm^{-1} (with adaptive filter)[1]
Response Time, (10-90%)	10 s; 30 s (with adaptive filter)[1]
Linear Dynamic Range	0 - 1200 Mm^{-1}
Internal Data Logger Capacity	8,192 lines (5 s = 1.4 days; 1 hr avg = 0.94 yr);
Power Requirement	11-14 V DC or 120/240 VAC, 12 Watt
Size	Rackmount: 17" w x 14.5" d x 5.5" h
Weight	18.6 lb (8.4 kg)

[1] User-configurable filtering that switches between a long and short running average depending upon signal variability. Specifications above are for default parameters: ΔB_{ext} = 15 Mm^{-1}, % Change = 5%, Short Filter = 4 pts (20 s), Long Filter = 12 pts (1 min).

5. Preliminary Results (Phase 1)

Particle loss within the photometer was investigated because of the significant number of angles in the flow path.

- NaCl solutions nebulized and dried to ~ 20% RH.
- Size distributions via optical particle counter (AlphaSense OPC-N2).
- Varied size distribution by changing NaCl concentration
- Loss of optically active particles determined by monitoring the CAPS-PMex with the APEx in-line or bypassed (Flow = 1.0 Lpm)



For Dp ≤ 0.7 micron: ~ 5% extinction loss

For Dp ~ 1 micron: ~ 15% extinction loss

- ***Most of the loss occurred within the solenoid valve (correctable)***
- ***Loss within the optical cell was always < 6%***

6. Measurement of B_{scat}

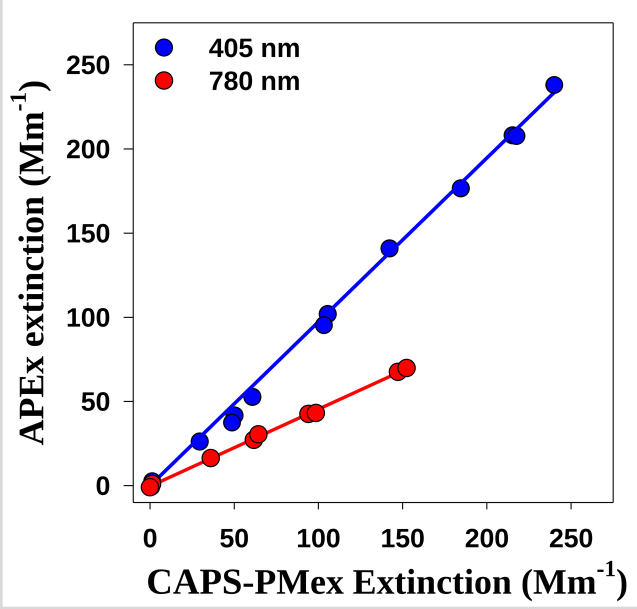
- Initial measurements of B_{scat} using 460 nm Polystyrene Latex Spheres (PSLs)
- Compared total extinction to that of the Aerodyne CAPS-PMex analyzer

$$Slope = \frac{\sigma_{scat}(APEx)}{\sigma_{scat}(CAPS - PMex)}$$

(CAPS-PMex: λ = 450 nm)

APEx λ, nm	Mie's Theory Slope[1]	Observed Slope
405	1.01	0.98
780	0.51	0.46

[1] σ_{scat} determined from Mie's theory calculation (Prahl, S., http://omlc.org/calc/mie_calc.html)



- ***Using simple optics (lens + apertures) to collect only the on-axis light leads to very good agreement for B_{scat}***
- ***Need to extend this experiment to other particle sizes.***

7. Field Observations

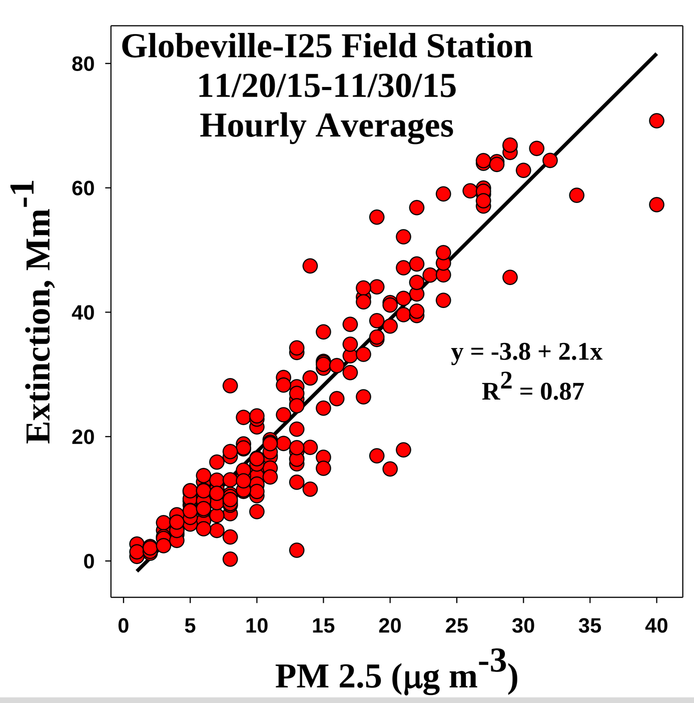
- Prior to APEx, a 2B Model 405 designed for NO_2 detection was operated at a roadside monitoring system without an inlet particulate filter.
- Observed extinction was due to both NO_2 and aerosols. NO_2 absorption was then subtracted out.

Extinction → Mass

$B_{ext} = \sigma_{ext}[PM2.5]$

Obs. Slope = σ_{ext} = 2.1 $m^2\ g^{-1}$

Corrected extinction exhibited good correlation with measured hourly PM2.5 and reasonable σ_{ext}.



Preliminary PM2.5 and NO_2 data provided by Colorado Dept. of Public Health and Environment (CDPHE).

APEx can provide a simple, robust instrument for relating optical extinction to mass concentration.

8. Future Directions

- *Further experiments to determine B_{scat} and B_{abs} for different aerosol types and sizes.*
- *Field study comparison of APEx with CAPS-PMex (along with PM2.5 measurements).*
- *Continue to improve instrument precision and sensitivity*
- *Proceed to Phase 2 developments (extension to multiple wavelengths, independent measure of B_{scat})*

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