Black Carbon in Dust and Sediment Particles: Quantification from Filter-Based Spectral Absorption Measurement

L.-W. Antony Chen[1,2,3] (antony.chen@unlv.edu), Yongming Han[3], Judith C. Chow[2,3], Junji Cao[3], John G. Watson[2,3]

[1]*Department of Environmental & Occupational Health, University of Nevada, Las Vegas, NV 89154, USA*

[2]*Division of Atmospheric Sciences, Desert Research Institute, 2215 Raggio Pkwy, Reno, NV, 89512, USA*

[3]*Key Laboratory of Aerosol Science & Technology, SKLLQG, Institute of Earth Environment, Chinese Academy of Sciences, Xi'an, 710075, China*

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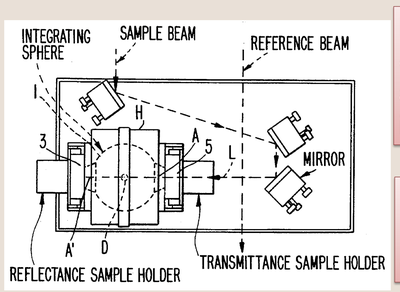
Introduction

Fugitive dust is an important component of tropospheric aerosol that contributes to Earth's radiaitve balance. Outbreaks of dust storms play an essential role in the long-range transport and deposition of dust particles. Urban aerosol, particularly organic and black carbon (OC and BC), on the route of dust storm can modify the chemical and optical properties of dust particles, and thus changing the climatic and environmental effects. Measuring absorption spectrum of fugitive dust over the solar wavelength region would help assess its mixing state and radiative forcing. This study introduces a practical method to characterize spectral absorption of dust particles resuspended onto Teflon-membrane filters. The method was evaluated with standard geological samples with known BC fractions, and then applied to urban dust and sediment samples acquired from northwest China to understand the urban impact on local soil/dust composition.

Optical/Spectral Method



- **Perkin Elmer Lamda 35 with spectral range of 250-1050 nm**

Measure total reflectance (R) & transmittance (T) of blank and loaded filters using an integrating sphere

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Calculate R and T of the dust layer using radiative transfer of a two-layer model

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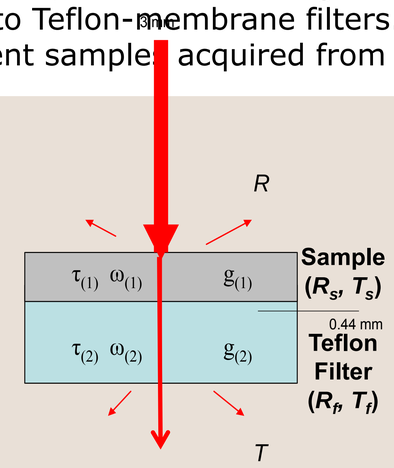
Determine absorption and scattering optical depth of the sample, based on inverse addition-doubling method

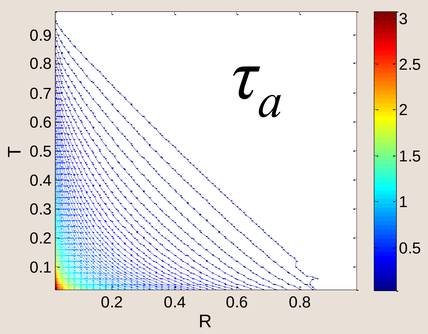


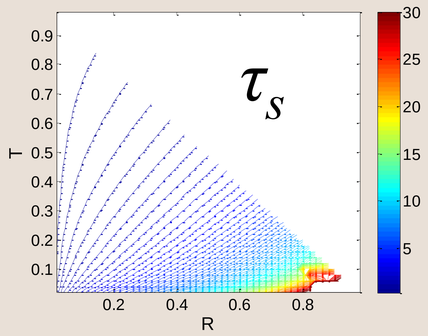
Inverse Adding-Doubling (IAD):

A numerical iterative method for solving absorption and scattering coefficients of a slab of uniform medium, based on total R and T measured by integrating sphere and adding-doubling radaitive transfer calculation (Prahl, 1993). The parameters examined: g = 0.72 ± 0.1, n = 1.25 ± 0.1

Definition

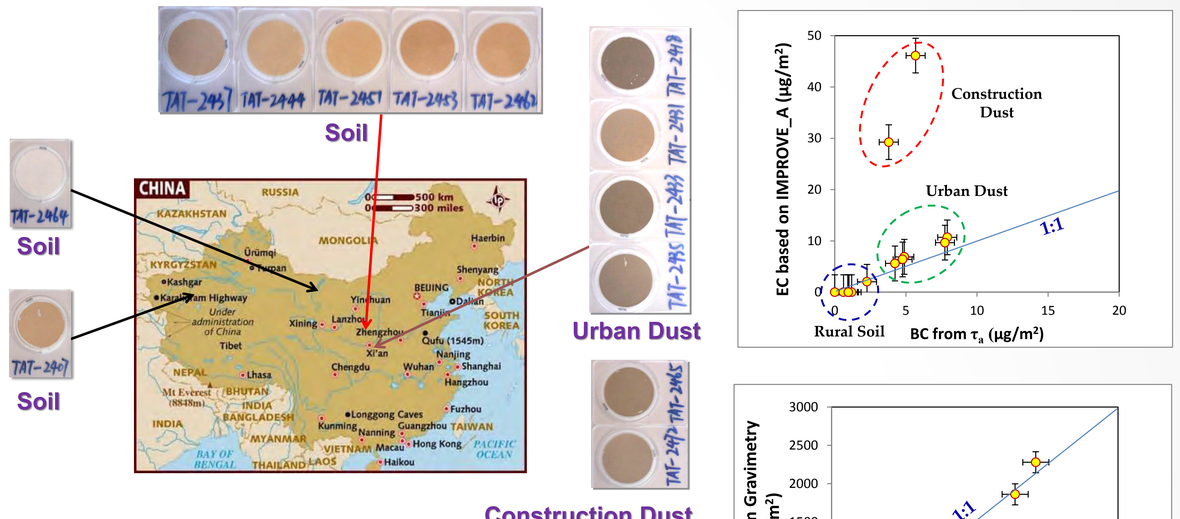
- τ, ω, g, n: optical depth, single scattering albedo, asymmetric factor, and bulk refractive index, respectively.
- Absorption optical depth (τ_a): $\tau_a = \tau_{(1)} \times (1 - \omega_{(1)})$
- Scattering optical depth (τ_s): $\tau_s = \tau_{(1)} \times \omega_{(1)}$





* Higher τ_a leads to lower R and T simultaneously. Higher τ_s corresponds to higher R but lower T. R ranges from 0.01 to 0.35 and T ranges from 0.03 to 0.9 in this study.

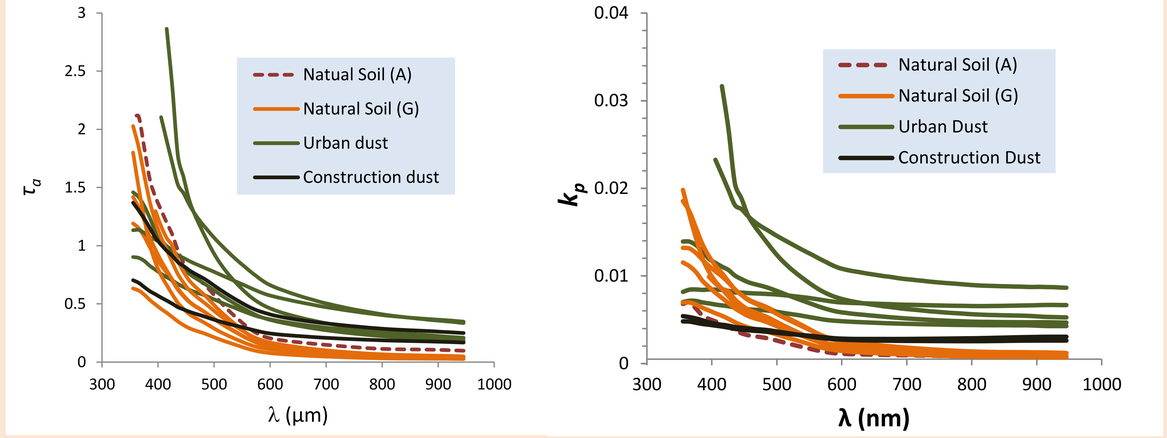
Environmental Samples Examined



- Urban dust samples (7) from Xi'an, China, including 2 construction dust samples
- Rural soil samples (8) from Xi'an, China, Gobi Desert, and Aksu, China (Taklamakan Desert).

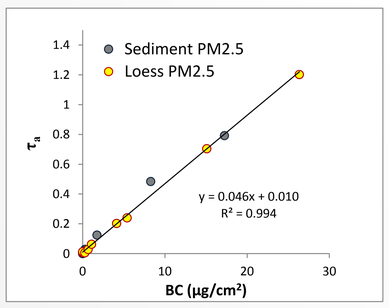
1) τ_s captures the variability in the GM mass, despite a higher loading of the environmental samples.
2) IMPROVE_A measures higher EC than BC from τ_a, especially for construction dust samples, likely due to contributions from calcite or other carbonates.
3) IMPROVE_A detects no EC in rural soil samples, while the optical method quantifies BC as low as 0.6 μg/cm². This suggests a lower detection limit of the optical method.

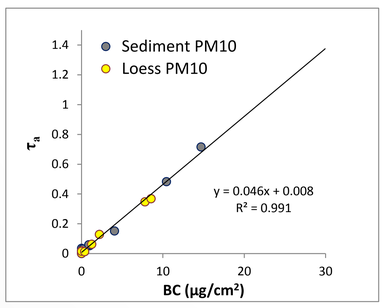
Spectral Absorption & Refractive Index

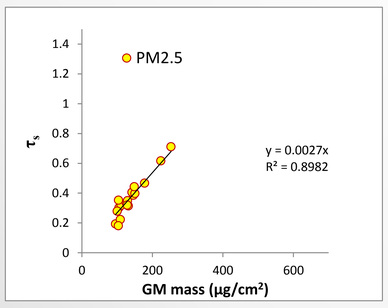


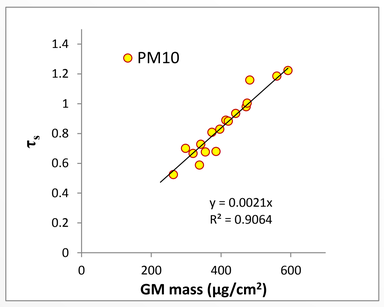
1) Spectral absorption is much higher in urban dust, consistent with higher BC fractions.
2) The absorption Angström exponent (AAE) for rural dust is 4.6±0.4 over 470-660 nm, slightly higher than 3.8 reported by Yang et al. (2009).
3) Imaginary refractive index (k_p) estimated from absorption show relatively constant values between 700 and 950 nm, consistent with the characteristics of BC and dust.
4) k_p at shorter wavelengths may be influenced by brown carbon in the dust/soil.

Evaluation with Standard Geological Material









- Standard geological material (GM) samples were prepared by:

1) heating loess and lake sediment samples to 800°C in air for 2 hours to remove OC, BC, and carbonate completely,
2) mixing several 10-g aliquots of the samples with 0–1-g carbon black (RS683, Cabot Corp., Boston, USA),
3) grinding, stirring, and submitting the mixed samples for resuspension,
4) quantifying exact BC fractions in the resuspended dust samples from the ratio of EC measured on quartz-fiber filter following the IMPROVE_A protocol (Chow et al., 2007) and gravimetric mass on Teflon filter.

- **BC absorption efficiency: 4.6±0.2 m²/g (900 nm), 7.5±0.2 m²/g (550 nm)**
- **GM $PM_{2.5}$ scattering efficiency: 0.27±0.02 m²/g (900 nm), 0.46±0.03 m²/g (550 nm)**

Conclusions

These results confirm the potential of using the optical method to quantify spectral light absorption of geological material and estimate BC content in the material. The substantial enrichment of BC in urban dust proves significant deposition of anthropogenic pollutants in northwestern China.

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• Prahl, S. A., van Gemert, M. J., & Welch, A. J. (1993). Determining the optical properties of turbid media by using the adding–doubling method. Applied optics, 32(4), 559-568.
• Yang, M., Howell, S. G., Zhuang, J., & Huebert, B. J. (2009). Attribution of aerosol light absorption to black carbon, brown carbon, and dust in China–interpretations of atmospheric measurements during EAST-AIRE. Atmospheric Chemistry and Physics, 9(6), 2035-2050.