Optical properties of particulate matter collected on glass fiber filters measured by spatially resolved reflectance spectroscopy

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More detailed and complete information on optical properties of particulate matter (PM) related to composition, size and structure can enable better classification and, at the same time, help to improve understanding of its impact on the climate, environment, human health and associated biological processes (Li 2022).

In this study, we investigate spatially resolved reflectance (SRR) spectroscopy for analysis of PM samples collected on glass-fiber filters by Aethalometer® AE33 (Aerosol Magee Scientific). The measurements are conducted with an optical fiber probe that utilizes a linear array of optical fibers (Fig. 1). The first fiber of the array is coupled to a broadband light source and the remaining fibers are used to collect spectra of the backscattered light at multiple distances from the source fiber, i.e., SRR spectra. The spectral information is collected in the visible and near-infrared range extending from 400 to 1000 nm.

The measured SRR spectra are modelled and analyzed by utilizing a light propagation model based on the Radiative Transfer Equation (RTE) and its numerical solution based on the stochastic Monte Carlo (MC) method, which we have implemented as a part of a highly efficient Python library PyXOpto (Bürmen 2022, Naglič 2022). The light propagation model accounts for the refractive index, absorption and scattering coefficients, and scattering phase function of the materials. The modeled SRR spectra are first parameterized in terms of the filter loading and optical properties of the glass-fiber filter and collected PM, and subsequently inverted to allow estimation of the relevant parameters directly from the measured SRR spectra. In this way, it is possible to recover the wavelength dependent absorption and scattering coefficients, and scattering phase function related quantifiers of the glass-fiber filter and collected PM. The inverse light propagation model is implemented using deep learning aided regression models that allow highly efficient estimation of the relevant quantities.

SRR spectra are first acquired and analyzed for unloaded glass-fiber filters to gain information on the optical properties of the glass-fiber filter, and to study the repeatability of SRR measurements and the related impact on the performance of the inverse models. Subsequently, the analysis is performed for SRR spectra acquired from glass-fiber filters loaded with PM samples of mineral dust and black carbon. The recovered information on the optical properties of PM can be related to the morphology and composition of the particles, aid source apportionment, and improve Earth's radiative balance estimation by climate models. The estimated optical properties can also be useful as a utility for continuous quality monitoring of glass-fiber filters.

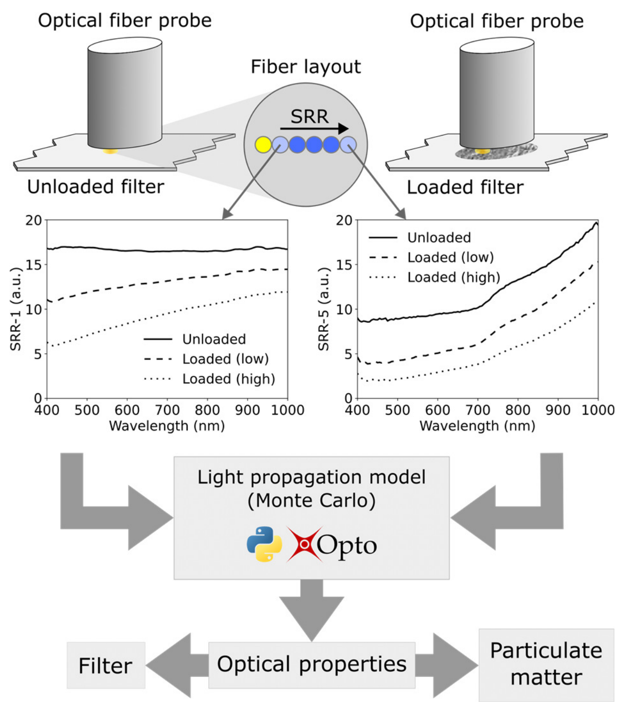

Figure 1. Measurement principle of SRR spectroscopy utilizing optical fiber probe and estimation of optical properties for glass-fiber filters and PM by RTE-based light propagation model.

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