Modelling of Aerosol optical profiles based on ground sampling and comparison with Caeli Multi-Wavelength Raman Lidar

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Abstract:

We estimate lidar-relevant optical properties based on aerosol physicochemical properties and relative humidity for the **2019 TROLIX campaign** in Cabauw. Vertical profiles of **extinction coefficient, backscatter coefficient and lidar ratio** were calculated from ground based aerosol measurements and profiles of temperature and relative humidity, from different altitudes at the Cabauw tower and radiosonde data.

We assume an external mixture of black carbon and secondary inorganic aerosol in the fine mode and an internal mixture of sea salt and mineral dust in the coarse mode.

Comparison with the aerosol optical properties retrieved by the CESAR Water Vapour, Aerosol and Cloud Lidar (Caeli) are presented, but show that the model tends to overestimate the lidar ratio.

Experiment:

Site and Trolix campaign:

Location: Cabauw station, located in the western part of The Netherlands (51.971° N, 4.927° E).
Intensive measurement period: Sept. 14 – Oct. 6, 2019, including ground-based and remote sensing measurements

Ground in situ instrumentation:

Particle size distribution: measured by using a scanning mobility particle sizer (SMPS) and combined with an Aerodynamic Particle Sizer (APS).
Chemical composition: The Secondary Inorganic Aerosol (SIA) mass concentrations were obtained with the GC-MS. Elemental analyses were performed using Teflon filters. And element carbon (EC) was measured with a Sunset using the EUSAAR-2 thermo-analytical protocol.
Meteorological data: obtained from the regular radiosonde station at De Bilt within a 40 km radius away from the site.

Lidar Remote sensing:

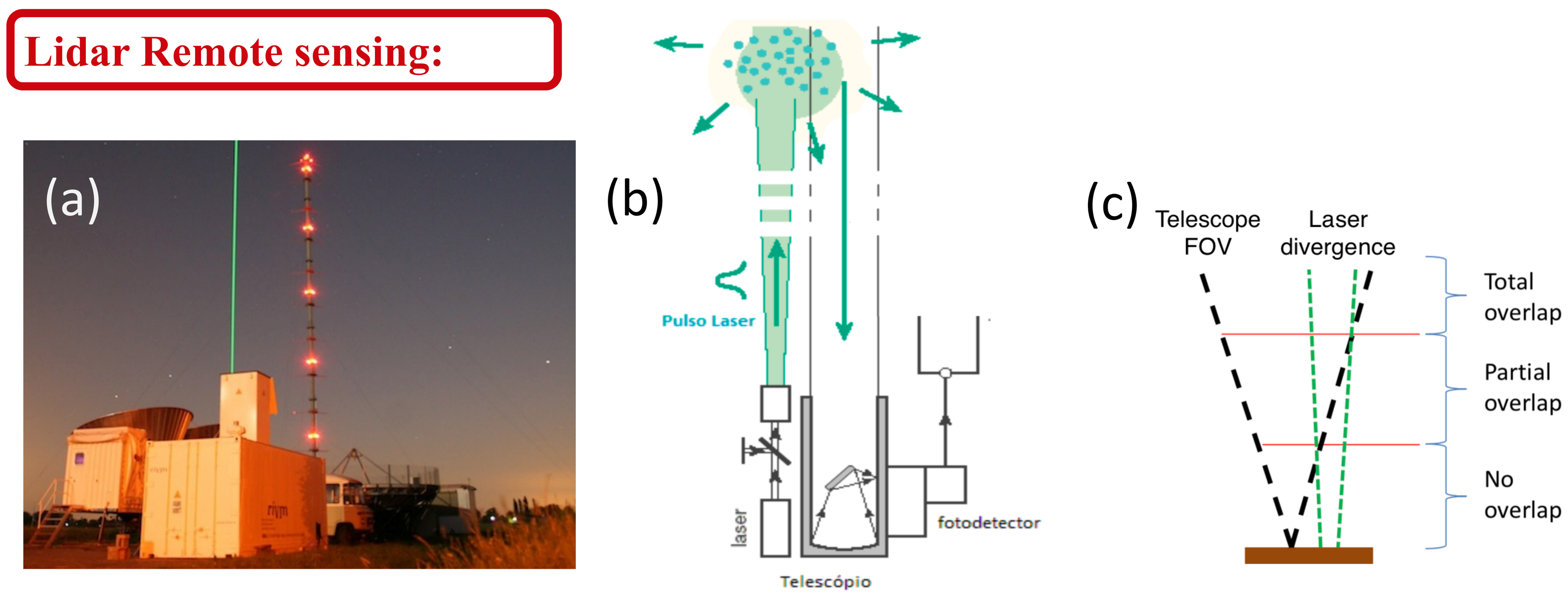
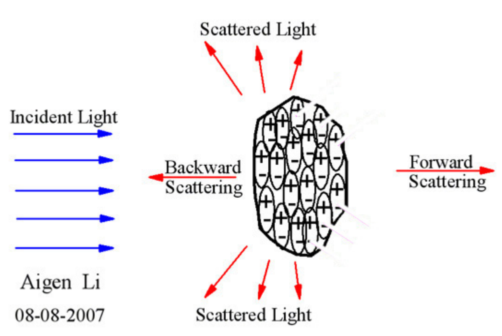


Fig.1. (a) The Raman lidar Caeli in operation at the Cabauw Experimental Site for Atmospheric Research (CESAR), close to the 213 m high meteorological tower. (b) Schematic of the Lidar remote sensing. (c) Overlap of the Lidar remote sensing.

Methodology:

Aerosol optical:

Lidar ratio(LR): is the ratio of extinction coefficient and backscatter coefficient. It has units of steradian and can vary from as low as 1 to about 100 sr, depending on the type of particles.



$$LR = \frac{\sigma_e}{\sigma_{back}} \qquad \sigma_e\text{: the extinction coefficient} \quad \sigma_{back}\text{: the backscattering coefficient}$$

Aerosol hygroscopicity:

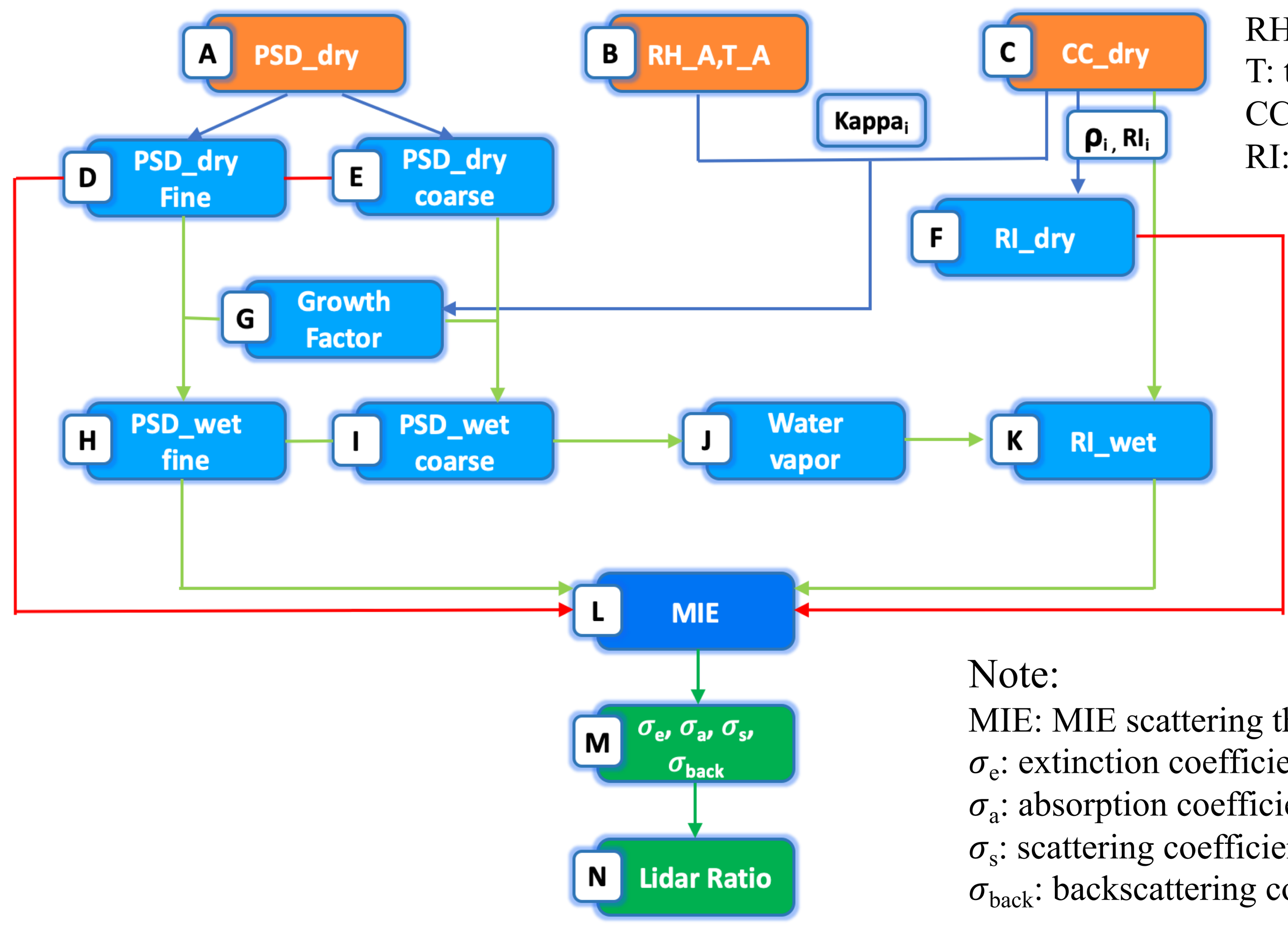
Hygroscopicity is the capacity to react to the moisture content of the air by absorbing or releasing water vapor. For a single particle, it can be characterized by the growth factor (GF), which is the ratio of the wet particle diameter at a high relative humidity to the corresponding dry diameter.

$$K_e = \exp\left(\frac{4T_S M_w}{RT\rho D_{dry}}\right)$$

$$GF = \left(\frac{K_{mix}RH}{K_e - RH} + 1\right)^{1/3}$$

Ts: surface tension of the solution/air interface(Ts =0.072 J m^{-2})
Mw: molecular weight of water(Mw=18)
R: universal gas constant(R=8.3145 J mol^{-1} k^{-1})
ρ : the density of water(ρ=1000kgm^{-3})
T: temperature(K) RH: relative humidity
Dwet: diameter of the wet aerosol.
Kmix: the kappa value of the mixture.

Modeling:



Note:
PSD: particle size distribution
RH: relative humidity
T: temperature
CC: chemical composition
RI: refractive index

Note:
MIE: MIE scattering theory
σ_e: extinction coefficient
σ_a: absorption coefficient
σ_s: scattering coefficient
σ_{back}: backscattering coefficient

Fig.3. the model components and steps based on the ground-based observations.

Results and Discussion:

Vertical profiles of aerosol backscattering, extinction coefficients and Lidar ratios:

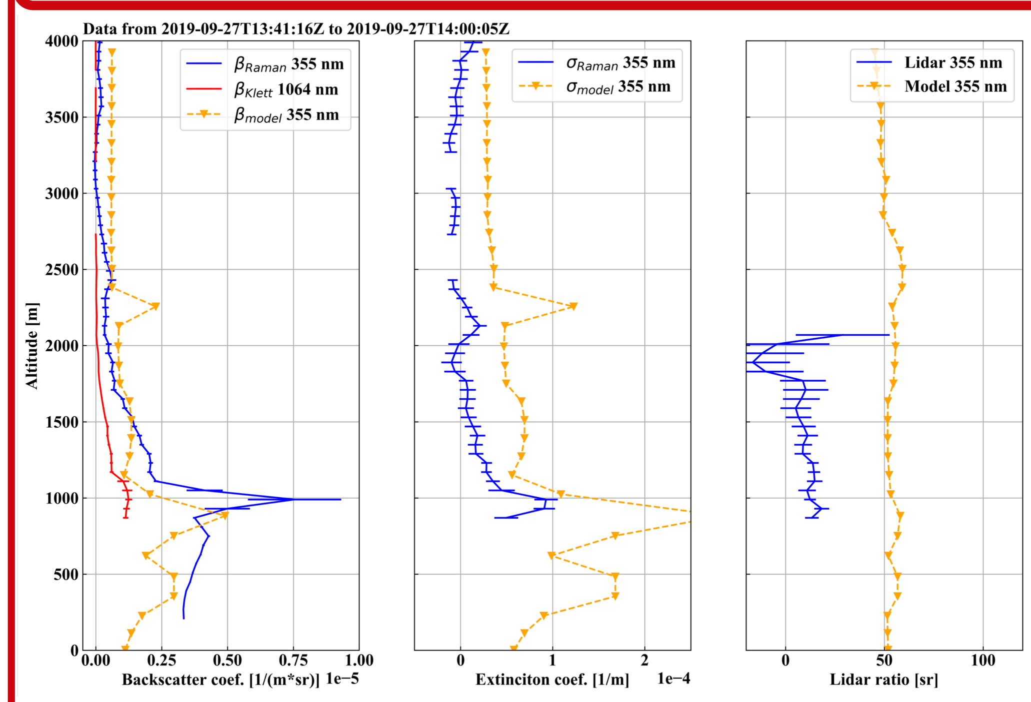


Fig.4. the comparison between the remote sensing (in color line) and modelling (in orange triangle) in the vertical profiles of aerosol backscattering, extinction coefficients and Lidar ratios.

- It showed that the extinction coefficients were overestimated from the modelling calculation based on the ground measurements. However, the model was validated by using a reported dataset gathered during June 2015(Fig.5d).

Chemical composition and Particle size distribution :

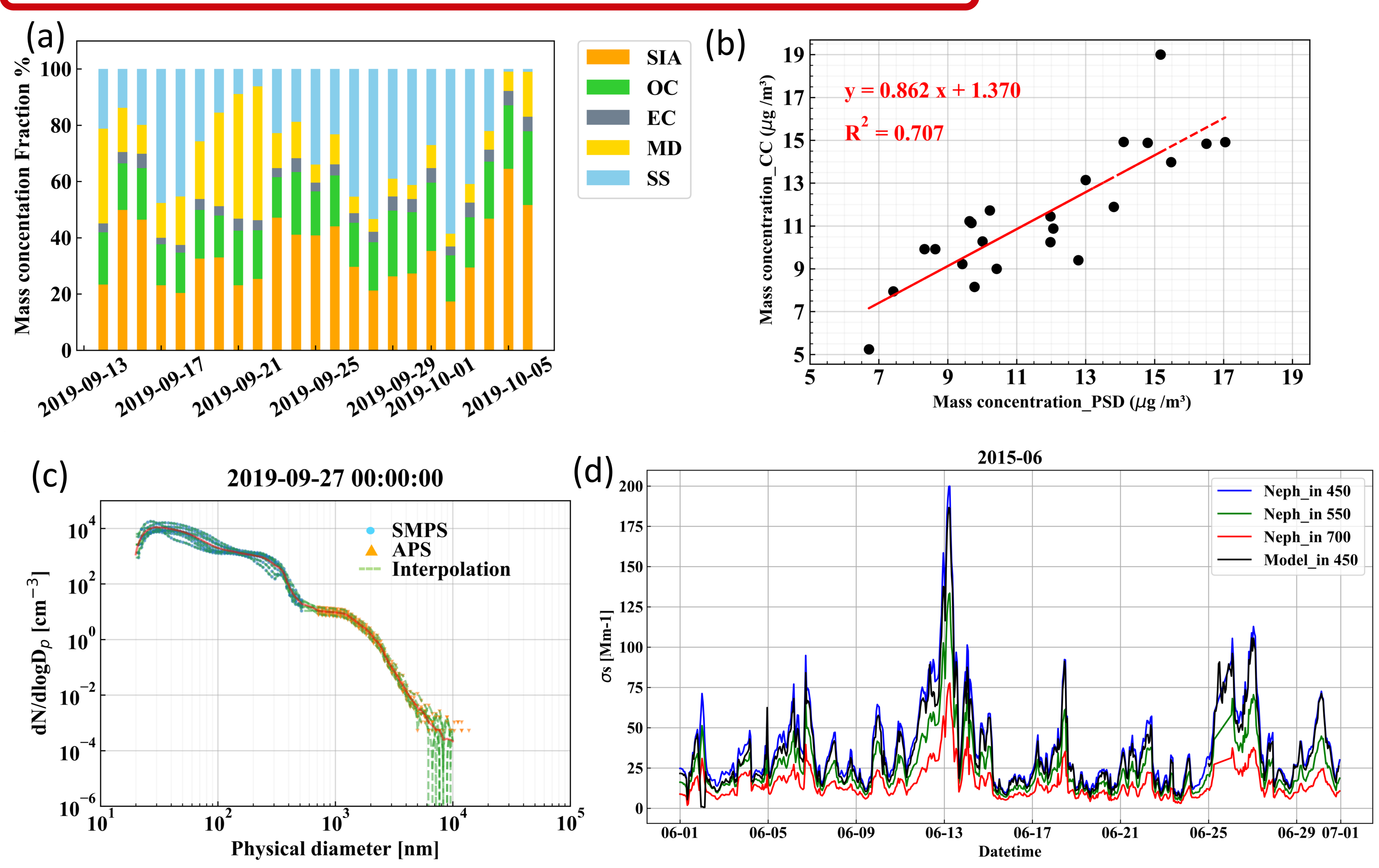


Fig.5. (a) The chemical mass concentration fraction during TROLIX campaign. (b) The total mass closure study between measured chemical composition and from the PSD. (c) PSD at dried condition during 2019-09-27. (d) Model validation with well measured data gathered during June 2015 at Melpitz Observatory.

Further study:

In order to complete this study, we expect to gather more reliable data in the upcoming Pre-Ruisdael May campaign. We aim to have High temporal resolution particle size distribution and the chemical composition, as well as the meteorological vertical profiles corresponding to the consistent time series. Further analysis can be easily performed by using the current model.

Reference:
[1] A Apituley, F Bosveld, H Klein Baltink. Caeli Water Vapour Raman Lidar Calibration At The Cabauw Experimental Site For Atmospheric Research. Conference: 26th International Laser Radar Conference, Place: Porto Heli, Greece, Year: 2012
[2] Li, Aigen. (2008). Optical Properties of Dust. Lecture Notes in Physics. 758. 10.1007/978-3-540-76935-4_6.
[3] Düsing, S., Ansmann, A., Baars, H., Corbin, J. C., Denjean, C., Gysel-Beer, M., Müller, T., Poulain, L., Siebert, H., Spindler, G., Tuch, T., Wehner, B., and Wiedensohler, A.: Closure of In-Situ Measured Aerosol Backscattering and Extinction Coefficients with Lidar Accounting for Relative Humidity, Atmos. Chem. Phys. Discuss. [preprint], https://doi.org/10.5194/acp-2021-21, in review, 202

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