Detection limits of a ground-based Lidar for new particles formed in the upper troposphere

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MOTIVATION

- Andreae et al. (2018) found the missing source of CCN in the Amazon region. ACRIDICON-CHUVA aircraft measurements showed ultrafine particles in the upper troposphere (UT) with higher aerosol number concentration than in the boundary layer (ABL).
- Can our ground-based lidar system detect these newly formed particles in the upper troposphere?

METHODOLOGY

- We use a radiative transfer model (LibRadtran) to simulate elastic lidar signals at 355 nm with the same intensity and S/N ratio as measured by our ground-based lidar;
- The particle optical properties (e.g. the asymmetry parameter, extinction coefficient) in the accumulation mode were calculated assuming spherical particles with log-normal size distribution (r_{eff}= 0.067 µm e σ=1.4 µm), with an index of refraction of 1.41 + i*0.013, based on co-located AERONET measurements.
- Mass concentration was calculated from number concentration considering a density of 1.5 g/cm^3
- Simulations were performed with and without aerosols, in order to estimate the instrument detection limits.

LIDAR EQUATION

$$P(z,\lambda) = P_0 \frac{c\Delta t}{2} A\eta \frac{O(z)}{z^2}\beta(z,\lambda) exp\left[-2\int_0^z \alpha(z',\lambda)dz'\right]$$

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CALIBRATION OF THE SIMULATED LIDAR SIGNAL

A priori we don't know exactly the characteristic parameters of the instrument as the initial pulse (P_0), the detection efficiency (η) and the overlap function (O). So we determine a constant of proportionality (κ) of the simulated and measured signal of the Lidar in 355 nm by a fit of the molecular model over the measured data between 6 and 9 km as can be seen in Figure 1. Where we assume to be absent of particulate matter.

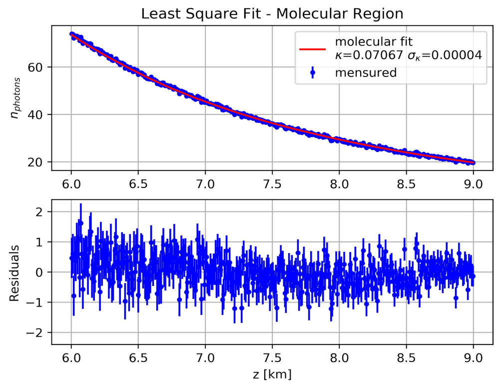

Figure 1. Fit of the molecular Lidar signal evaluated by libRadtran over the observational data of the instrument between 6 and 9 km. The legend shows the parameter κ and it's uncertainty σ_κ.

SIMULATION WITH THE ACCUMULATION AEROSOL

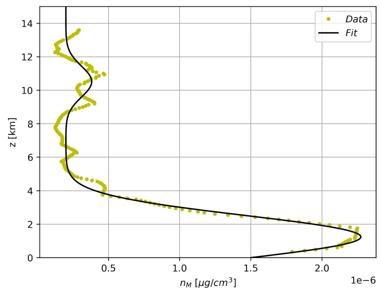

Figure 2. Fit of the accumulation mode aerosol mass concentration

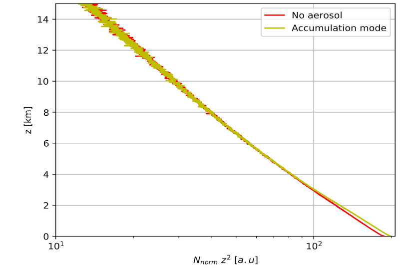

Figure 3. 2 hours simulated mean lidar signal normalized and corrected by distance up to 15 km (on logarithmic scale) due only molecular scattering (red) and considering the accumulation mode aerosol (yellow)

χ^2 HYPOTHESIS TESTING TO DETECTION OF THE AEROSOL PRESENCE

- Molecular model was rejected below 4 km as can be seen by the high values of χ^2_{red} (much larger than one) in Figure 4.
- We detect this aerosol in low layers where the mass concentration is larger, but not in the UT.
- Will be much more difficult to detect ultrafine particles in the UT

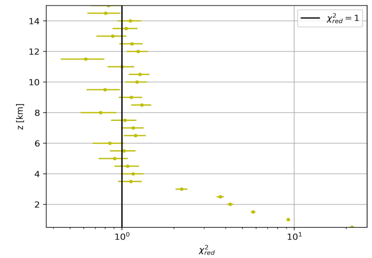

Figure 4. χ^2_{red} (on logarithmic scale) obtained by the molecular fit over the accumulation mode aerosol signal in ranges of 500 m

FUTURE PLANS

- Performing the simulations for the Aitken mode particles
- Investigating whether a larger time averaging and/or a realistic upgrade of the lidar system (telescope size, laser power, etc.) could allow the detection of these particles.

REFERENCES

Andreae, M. O., et al. Aerosol characteristics and particle production in the upper troposphere over the amazon basin, Atmospheric Chemistry and Physics, 18 (2), 921–961, 2018.