Estimation of the microphysical properties of volcanic ash with Raman lidar

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Motivation

Measurement of the microphysical properties of ash are required to estimate its impact on aviation. The RACHEL system observed the Eyjafjallajökullash plume over CFARR in southern England, providing high temporal and vertical resolution observations of aerosol scattering from which it is hoped the microphysical properties can be estimated.

Lidar retrieval

First, an optimal estimation retrieval [1] of the aerosol extinction and backscatter, α and β, is performed. Daytime observations are not presented here due to excessive noise. The Raman lidar equations are used as a forward model for energy observed from a range bin i,

$$E_{el}(R_i) = C_{el}(R_i)[\beta_m(R_i) + \beta_a(R_i)]\,\mathcal{T}^2 \qquad E_{ra}(R_i) = C_{ra}(R_i)\mathcal{T}^{1+\frac{\lambda_L}{\lambda_X}}$$

$$\mathcal{T} = \exp\left[-R_0\alpha_0 - \frac{\Delta R}{2}\left(\alpha_0 + \alpha_i + 2\sum_{j=1}^{i-1}\alpha_j\right)\right],$$

where ΔR is the bin length, C describes the known sensitivity of the instrument, and subscript indicates molecular or aerosol scattering.

Retrieved aerosol optical thickness, $\mathcal{T}$, is found to be in good agreement with AERONET measurements at the same site.

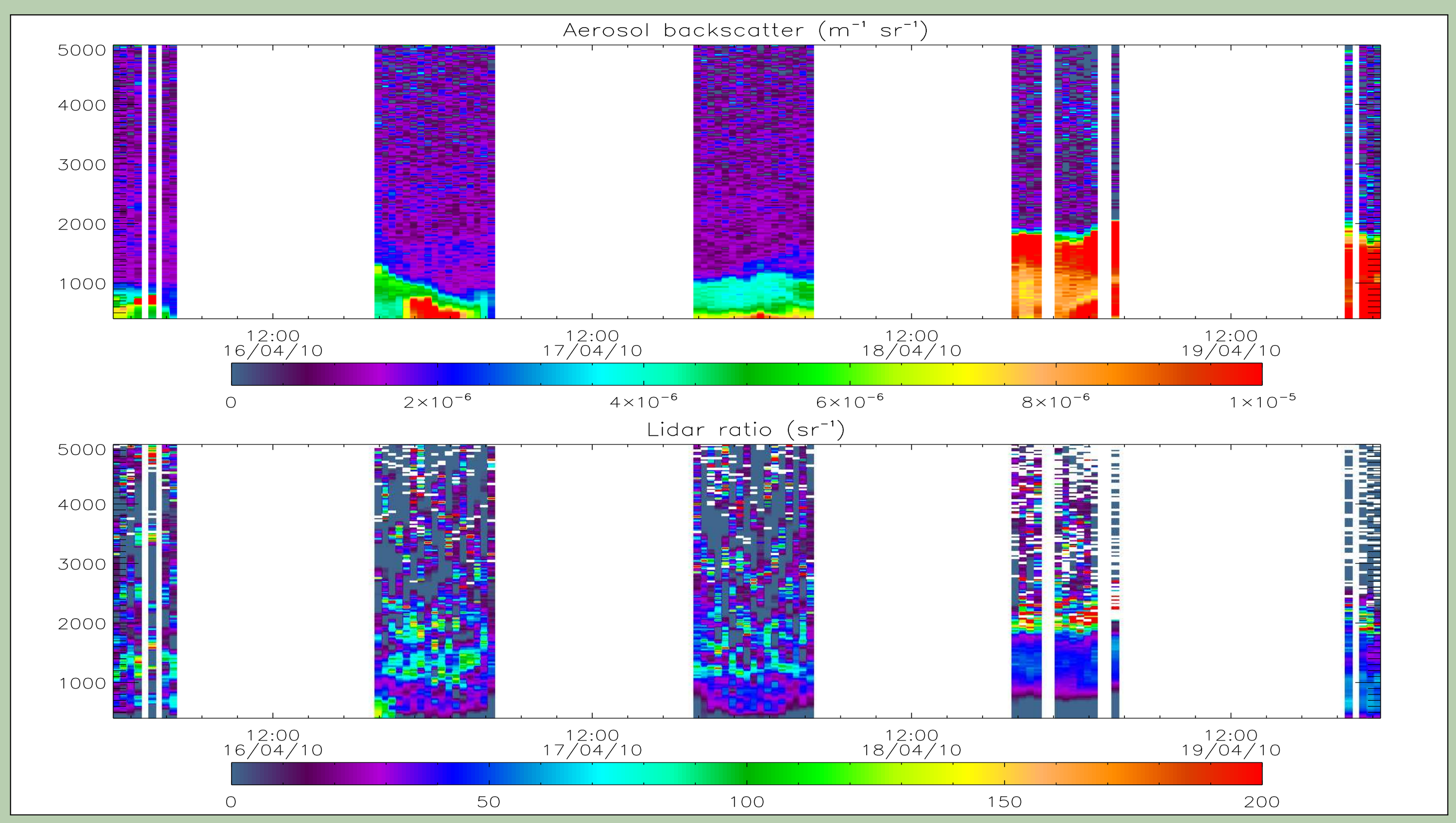

Figure 1: Retrievals from CFARR. A high depolarization ratio indicated ash was present after 12:00 on April 16th. Lidar ratio $= \alpha/\beta$. Height in metres plotted vertically.

Scattering look-up table

A simple means to estimate mode radius and number density from α and β was compiled assuming randomly oriented spheroidal particles [2] with radii $> 0.1\,\mathrm{mm}$. A refractive index of $1.52 + 0.008i$ [3], aspect ratio of 1.8 [4], and mode variance of 0.56 [5] are assumed, plotted in green opposite. Number density is then determined from the backscatter. This method neglects the impact of any non-ash aerosol and the error resulting from this assumption has not been assessed in this initial investigation.

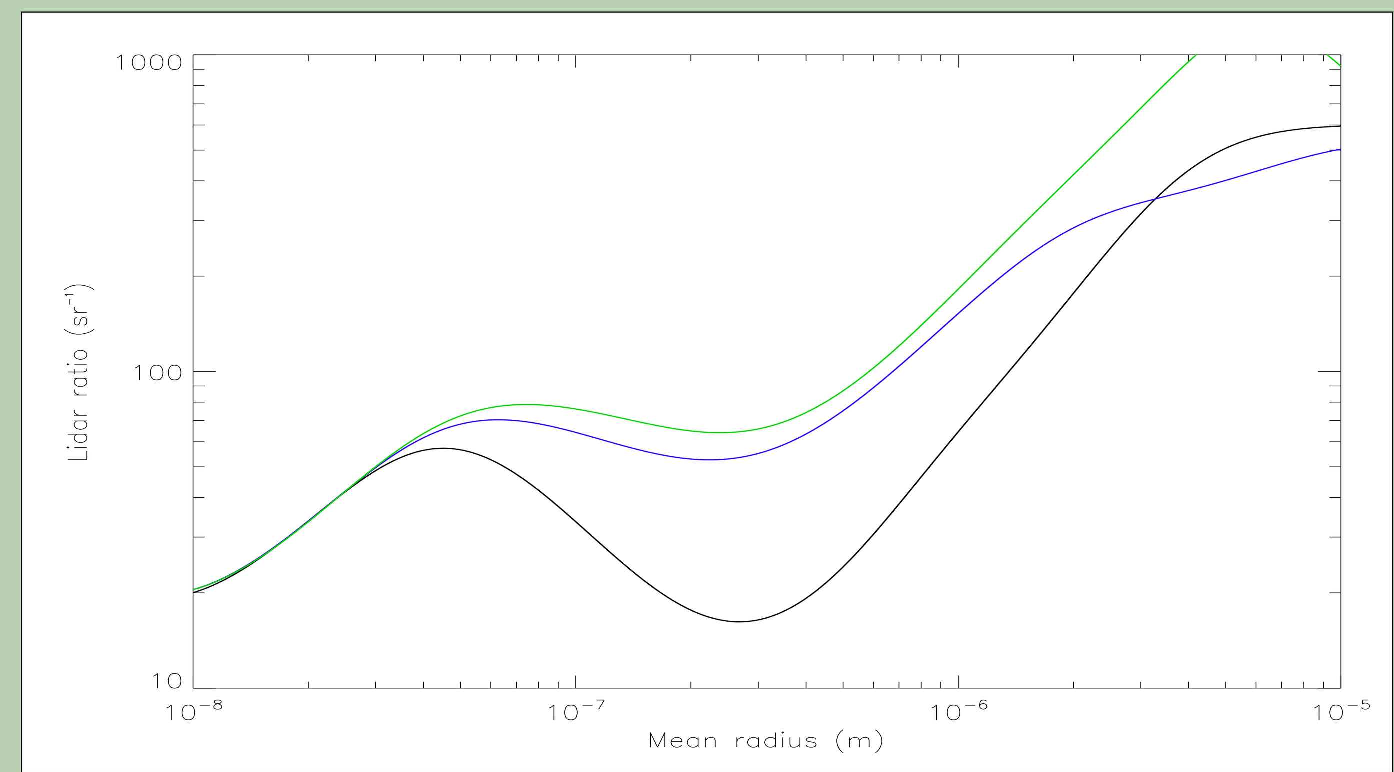

Figure 2: Calculated mapping of lidar ratio onto mode radius for aspect ratios of 1.0 (black), 1.7 (blue), and 1.8 (green).

Results

The retrieved ash lidar ratio of 70 – 80 is agreement with other observations [6, 7]. The ash is not as thoroughly mixed through the mixed layer as observed by other instruments at this site, indicating that this instrument's calibration needs further investigation. Regardless, the mode radii and mass loadings estimated from it are broadly in line with the literature on the night of 18–19 April, 2010. The region of aerosol observed earlier in the week presenting a larger mode radius above the primary concentration is likely due to the dominance of non-ash aerosol, though this should be assessed.

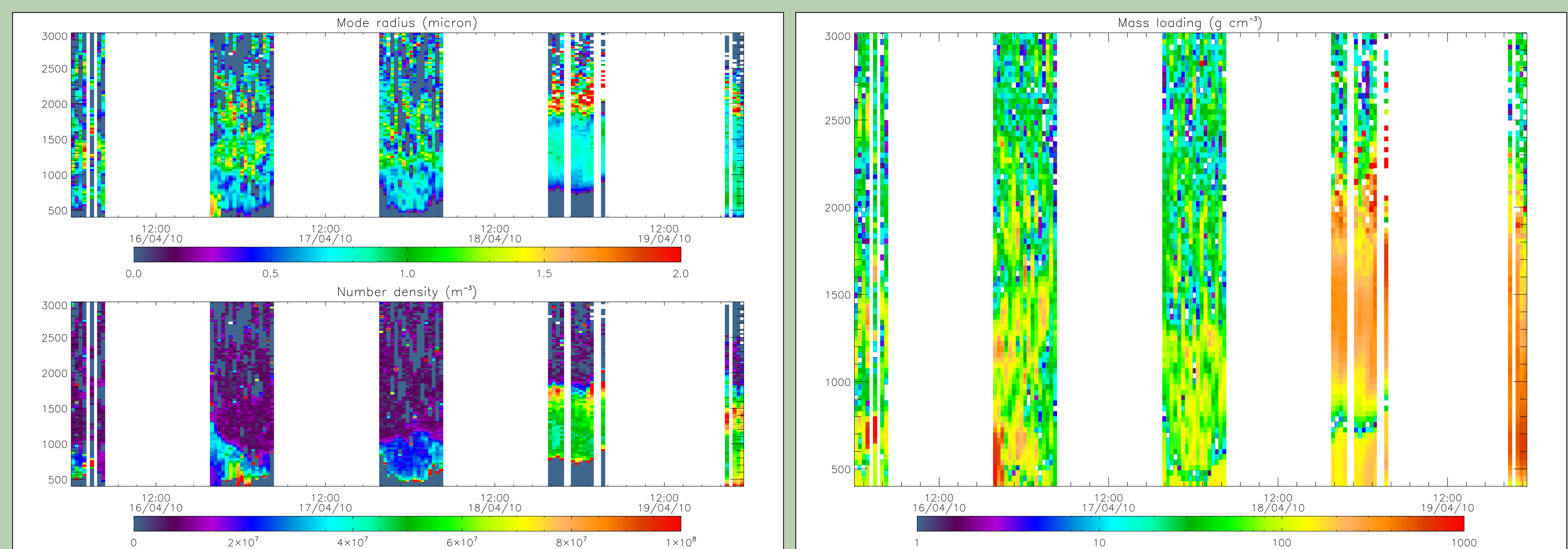

Figure 3: *Left* — Mode radius and number density derived from fig. 1. *Right* — Simple estimate of mass loading, assuming spherical particles with a density of $2300\,\mathrm{kg\,m^{-3}}$ [6].

Discussion

The calibration is the dominant source of error, such that uncertainty on the products shown here can be as great as $1000\,\%$, though is mostly around $50\,\%$. Improvements to this process are ongoing. However, it has hopefully been demonstrated that physically reasonable values can be retrieved by this method for ash of known refractive index. Of course, for truly unknown aerosol, lidar observations at several wavelengths and a more involved retrieval including scattering theory would be necessary.

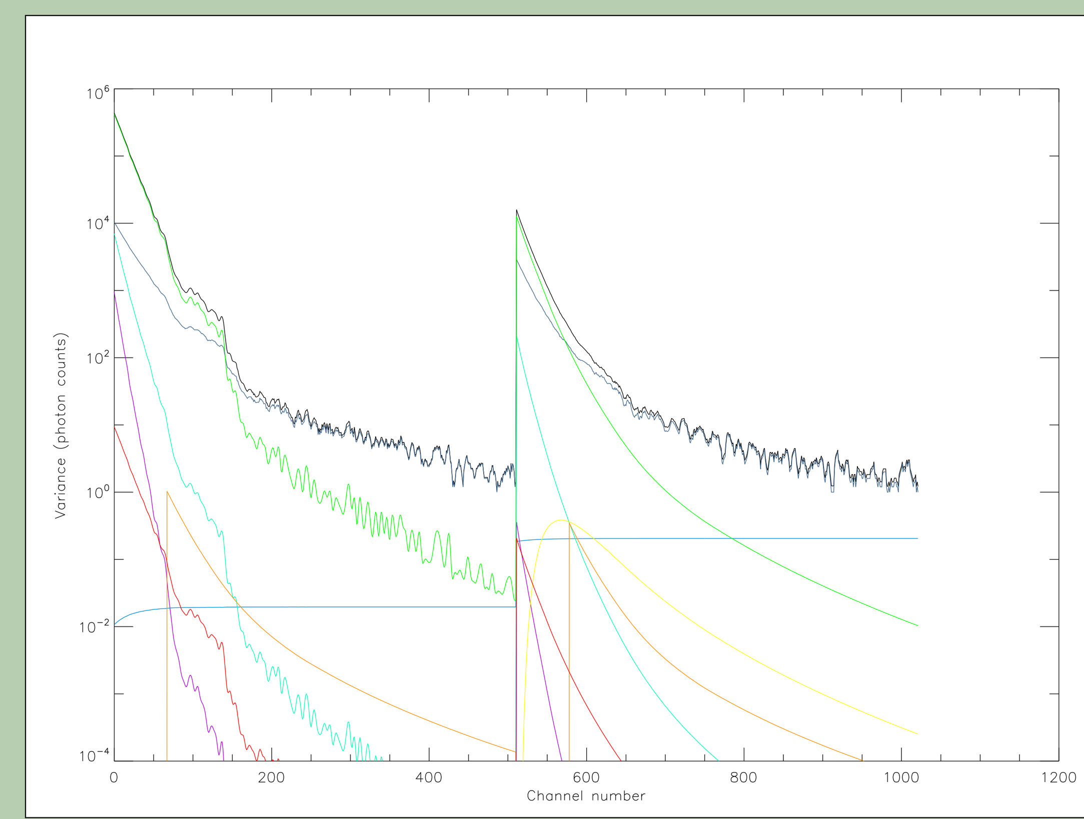

Figure 4: Contributions to the total retrieval error budget (black). The most relevant are the instrument calibration (green), measurement noise (grey), and detector non-linearity (teal).

References

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