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Estimating mass concentrations of volcanic ash using lidar and Sun photometer observations

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During the eruptions of the Eyjafjallajökull volcano (Iceland) in spring 2010, networks of lidar systems (e.g., EARLINET) proved to be useful for monitoring volcanic ash plumes and the validation of ash transport models. The topic of the present paper is the estimation of mass concentrations of volcanic ash from measurements of a sophisticated lidar system; the mass concentration is a relevant parameter for the assessment of ash-related flight safety impacts. In general, for the retrieval of microphysical aerosol properties from remote sensing measurements, optical modeling of ash particles is required. The microphysical properties of volcanic ash aerosols, however, are rather complex: ash aerosols cover a wide spectrum of particle sizes and shapes, and have variable chemical composition, making optical modeling and the retrieval of microphysical properties a challenging task.

We retrieve mass concentrations of Eyjafjallajökull ash from measurements of the lidar systems MULIS and POLIS in Maisach (near Munich, Germany); for this, spectral optical properties in the λ-range from 355 nm to 1064 nm, i.e. extinction and backscatter coefficients, and linear depolarization ratios, are used as input for an inversion algorithm. The basic idea of the inversion is to find model aerosol ensembles with optical properties that are in agreement with the lidar measurements. The model ensembles consist of spheroids having a log-normal size distribution and a complex refractive index. The microphysical properties of the ensembles are specified by several parameters which are varied within wide ranges using a Monte Carlo approach. The initial result of the inversion is a distribution of different aerosol ensembles which agree with the lidar measurements. From this distribution, distributions of arbitrary ensemble properties can be derived, e.g., the distribution of mass concentrations. This inversion is applied to measurements in the morning of 17 April 2010, when the peak of the ash-related extinction coefficient was reached with values around $0.75\,km^{-1}$ at $\lambda = 532$ nm. The lidar inversion retrieves a mass concentration of $1.1\,mg\,m^{-3}$ (0.65 to $1.8\,mg\,m^{-3}$), assuming an ash mass density $2.6\,g\,cm^{-3}$.

Due to assumptions and low sensitivity for large particles, a cross check of this inversion result is advisable; large ash particles could contain a significant portion of the mass, but might be missed by the lidar retrieval. We use radiances in the aureole of the Sun for this cross check because they are more sensitive to larger particles and less affected by uncertainties about particle shape and chemical composition. We model aureole radiances and compare them to measurements of the CIMEL Sun photometer located in Munich. The two-layer structure of the aerosol on 17 April 2010 and the uncertainties of the aerosol properties are considered (resulting in $>$12000 model runs). The comparisons with the CIMEL measurements confirm the mass concentration from the lidar inversion approach. We conclude that synergistic utilization of high quality lidar and Sun photometer data, in combination with realistic aerosol models, is a promising approach for ash mass concentration retrievals.