Cirrus Extinction and Lidar Ratio Derived from Raman Lidar Measurements at the Atmospheric Radiation Measurement Program Southern Site

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Introduction

Range resolved microphysical properties and extinction coefficient in cirrus clouds are critical for assessing the impact of cirrus on climate. Vertical profiles of cirrus extinction are important parameters for radiative flux and heating rate calculations. The extinction-to-backscatter ratio (also called lidar ratio) provides information on the transmission and reflection properties of cirrus clouds and also on the ice crystal properties due to its dependence on the shape, size and orientation of the particles. In addition, the lidar ratio is required for validation of extinction retrievals from single wavelength elastic lidars. The availability of a reliable data set of lidar ratio for different cirrus types and conditions will greatly improve the quality of the cirrus properties derived from space, which will produce a global climatology of cirrus range resolved properties.

The Atmospheric Radiation Measurement (ARM) program's Raman Lidar (CARL), located at the Southern Great Plains site, provides the opportunity for independent measurements of vertical profiles of extinction and backscatter coefficients of optically thin clouds, and thus of their extinction-to-backscatter ratio. The accumulated data set spans over more than 8 years and can be used to derive climatologically significant data set of range resolved cirrus cloud properties, including extinction and lidar ratio. A work to derive those parameters from the Raman lidar measurements is in process.

Calculation of Extinction Coefficient from Raman Lidar Measurements

In order to derive extinction coefficient form elastic lidar measurements the so-called Klett inversion method is used [1]. This method, however, has the disadvantage that two physical quantities, the aerosol backscatter and extinction coefficients must be determined from only the elastic backscatter. This is not possible without assumptions about the relationship between the two and an estimate of a reference value of the aerosol extinction. These data are usually hard to assess and cause large uncertainties in the derived aerosol extinction coefficients. In contrast, the inelastic Raman backscatter signal is affected by aerosol extinction but not by aerosol backscatter. Therefore analysis of the Raman lidar signal alone permits the determination of the aerosol extinction.

The formalism to derive extinction from Raman lidar measurements was developed by Ansman et al. [2]. According to [2] the aerosol extinction coefficient is obtained from the slope of the Raman nitrogen profile compared to the atmospheric density profile as:

$$\alpha(\lambda_L, z) = \frac{\left(\frac{d}{dz} \left\{ \ln\left[\frac{N(z)}{z^2 P(z)} \right] \right\} - S_{mol}(\lambda_L, z) - S_{mol}(\lambda_R, z) \right)}{1 + \left(\frac{\lambda_L}{\lambda_R} \right)^k}, \tag{1}$$

Where $\alpha(\lambda_L,z)$ is the cloud extinction coefficient, $N(z)$ is the atmospheric number density, z is the altitude of the measurement, S_{mol} is the molecular extinction coefficient, P(z) is the molecular lidar signal and λ_L and λ_R are the laser and the Raman shifted wavelengths, respectively. The wavelength dependence of the aerosol extinction coefficient is described by the parameter k. For aerosol particles with diameter comparable to the measurement wavelength k=1, while for particles considerably larger than the measurement wavelength, k=0. The main difficulty in deriving the extinction coefficient form equation (1) is associated with the calculation of the slope

$$\frac{d}{dz} \left\{ \ln\left[\frac{N(z)}{z^2 P(z)} \right] \right\}$$

since the molecular signal, which can be quite noisy, usually requires significant averaging and smoothing before slope calculations can be performed.

The Raman lidar at Southern Great Plains (CARL) transmits laser wavelength of 355 nm and measures the backscattered elastic (aerosol) return at the same wavelength as well as the water vapor and nitrogen Raman shifted returns at 408 and 387 nm, respectively. In addition, the aerosol return at 355 nm is split into co-polarized and cross-polarized components, enabling the computation of the depolarization ratio. (More details on CARL can be found at [3-5]). In order to derive cirrus extinction coefficient according to Eq. (1), the molecular nitrogen return at 387 nm is utilized and value of k=0 is assumed.

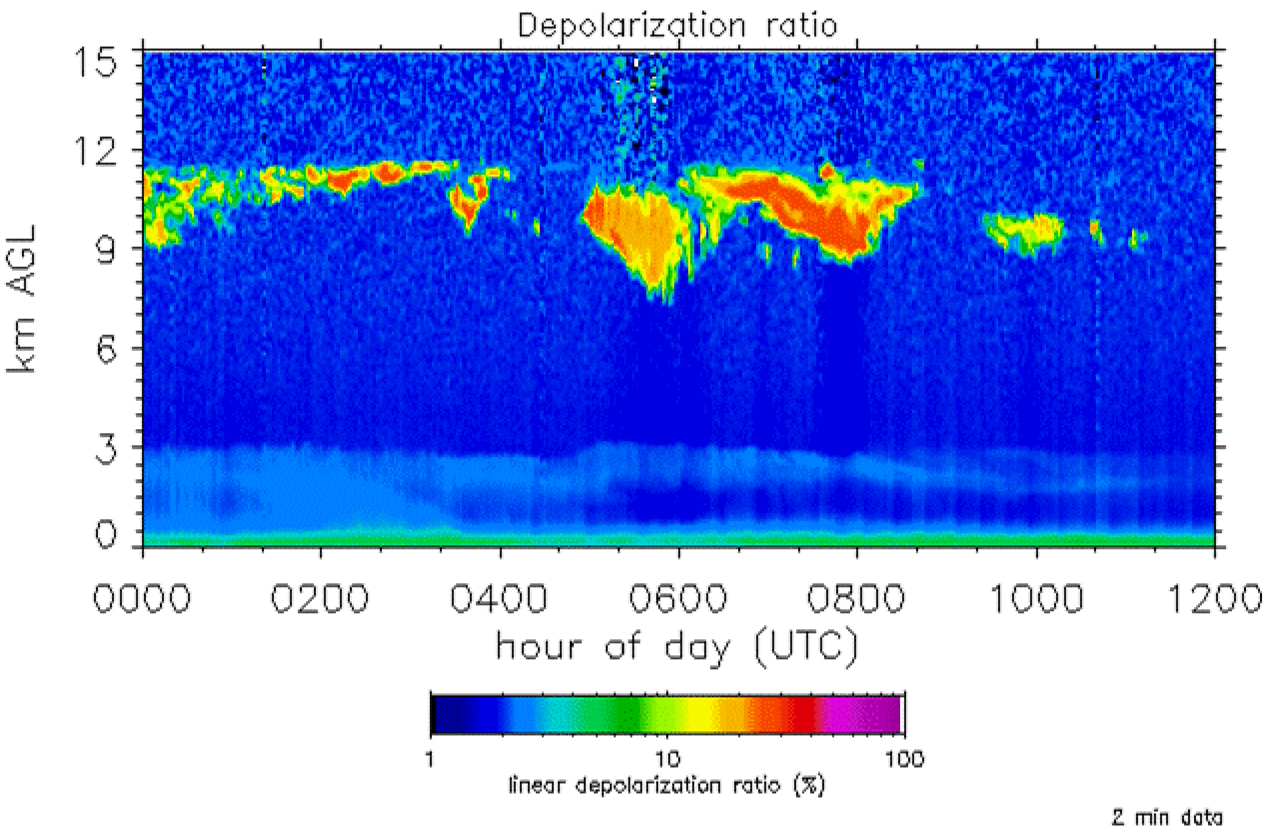

Figure 1. Depolarization ratio derived for a cirrus cloud observed by CARL on March 12, 2005.

Figure 2 and Figure 3 depict the extinction coefficient and the relative error of the extinction for a cirrus cloud observed on March 12, 2005. The particle depolarization and the lidar ratio are also shown on Figure 1 and Figure 4, respectively. Prior to extinction calculations the laser shots from the nitrogen channel have been summed in a 2 min and 37.5 m bins. Additionally, the nitrogen signal has been smoothed with 5 points sliding average. This temporal and vertical resolution allows the extinction to be calculated up to the top of the cloud with error less than 25%.

It should be noted, however, that in order to derive reliable profiles of extinction and lidar ratio, the lidar signal or the derived extinction coefficient need to be corrected for multiple scattering effects, which are known to lead to underestimation of the extinction in the presence of large particles [ex. 6], particularly at the cloud boundaries. The magnitude of a multiple scattering correction depends on the measurements geometry (the laser beam divergence, the receiver field-of-view and the distance between the lidar and scattering medium) as well as on the properties of the scattering medium (optical depth and size of the particles). We are working on implementation of a multiple scattering correction for our extinction calculations.

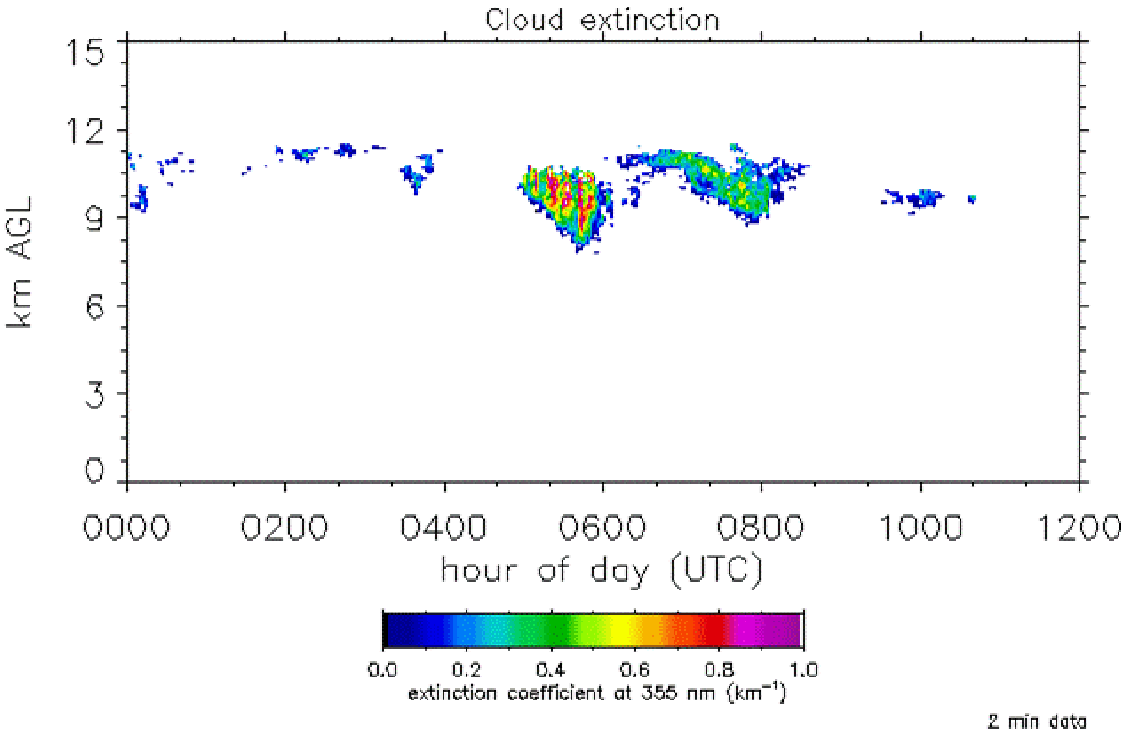

Figure 2. Extinction coefficient derived according to Eq. (1) for the cirrus cloud depicted on Figure 1.

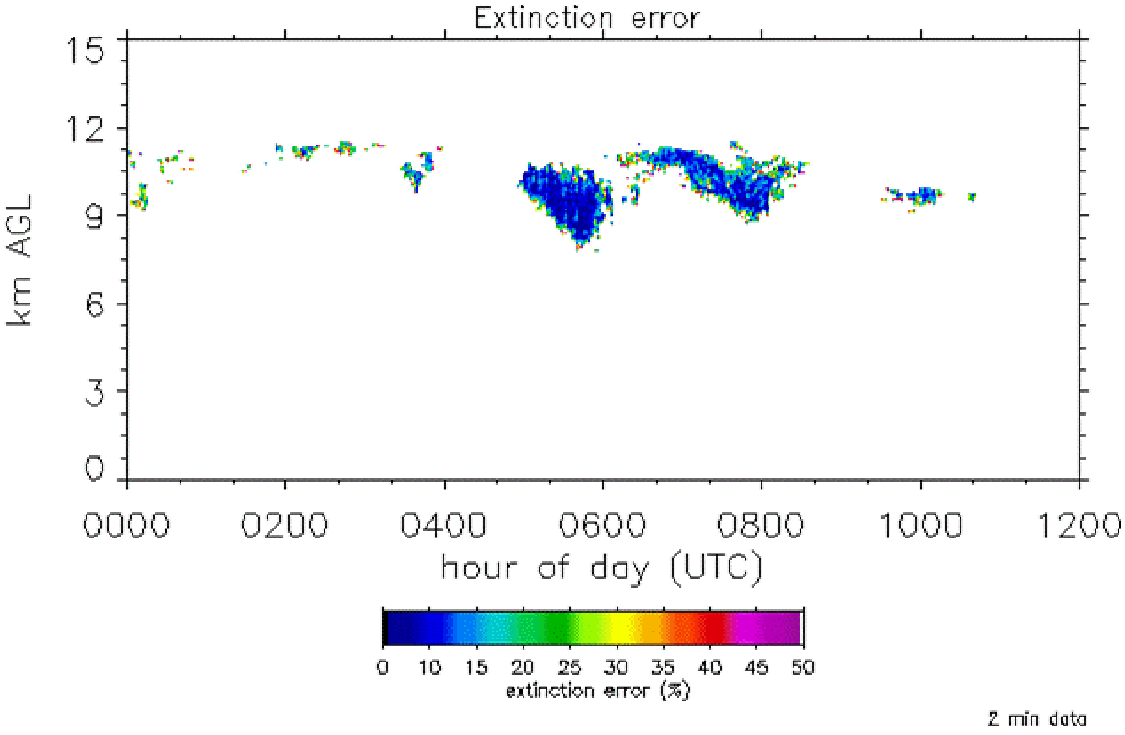

Figure 3. The relative error of the extinction coefficient shown on Figure 2.

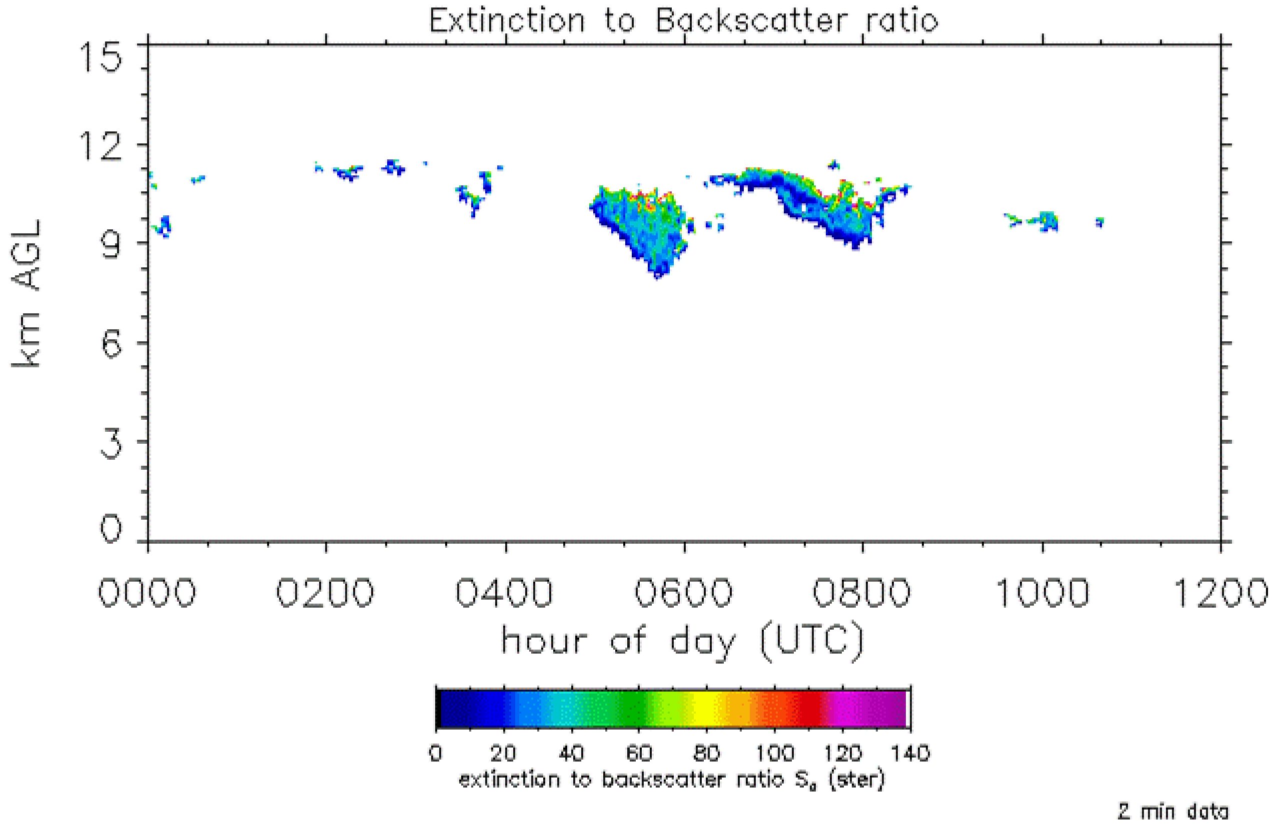

Figure 4. The extinction-to-backscatter ratio derived for the cirrus cloud shown on Figure 1.

Future

The utilization of the long-term data set collected by CARL for deriving cirrus cloud extinction and lidar ratio would have significant impact on the climatology of those parameters. Deriving cirrus extinction profiles from CARL is one of the recommendations of the Cloud Properties Working Group as well.

Our future efforts will be concentrated on deriving appropriate multiple scattering correction for our data, accumulating a multiple year dataset of bulk as well as range resolved cirrus extinction and lidar ratio and utilizing the data for the investigation and parameterization of cirrus microphysical properties.

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