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INFERENCE OF CLOUD ALTITUDE AND OPTICAL PROPERTIES FROM MAX-DOAS MEASUREMENTS

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Abstract

Multi-Axis Differential Optical Absorption Spectroscopy (MAX-DOAS) is a widely used technique for the detection of atmospheric trace gases, e.g. NO2, SO2, but also for the oxygen collision complex O_4, whose atmospheric distribution is well known. By comparing measured O_4 differential slant column densities (dSCDs) with modelled ones, information on aerosol distributions and optical properties can be gained[1,5]. In combination with a radiative transfer model[4], an inversion of measured dSCDs allows the retrieval of vertical aerosol extinction profiles and properties.

Instrumentation

Differential Optical Absorption Spectroscopy (DOAS)

DOAS is based on the separation of narrowband differential absorption structures from broadband absorption and scattering. The differential absorption structures are characteristic for each species which allows a reconstruction of the measured spectrum to determine the concentrations of different absorbers at the same time.

$$I(\lambda)=I_0(\lambda)\cdot\exp\left(-\sum_i \sigma_i(\lambda)\cdot\bar{c}_i\cdot L-\varepsilon_b(\lambda)\cdot L\right) \Rightarrow \ln\left(I_0(\lambda)/I(\lambda)\right)=\sum_i \sigma_i'(\lambda)\cdot a_i+P(\lambda)$$

Molecular Absorption; Scattering (Rayleigh, Mie); s_i: absorption cross section of species i with concentration $\bar{c}_i$; measured optical depth; Fitted model

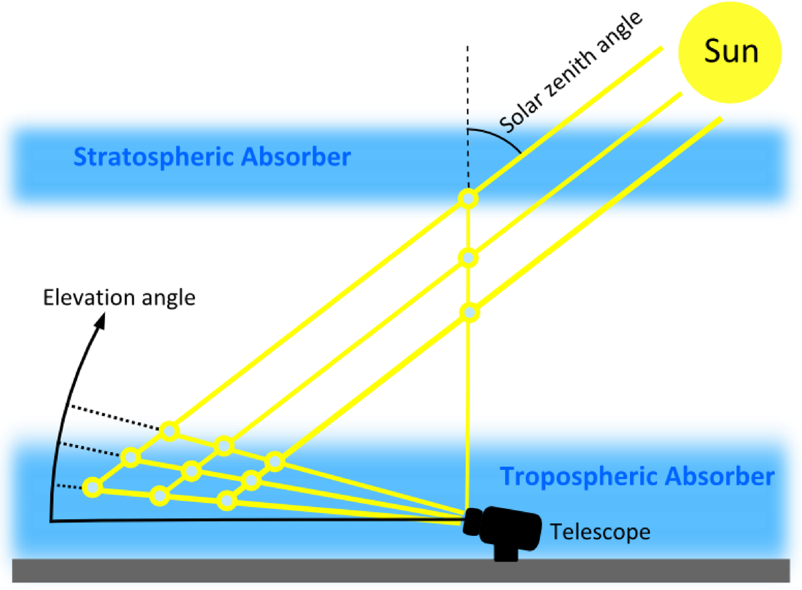


Fig.1: Principle of MAX-DOAS measurements[2]

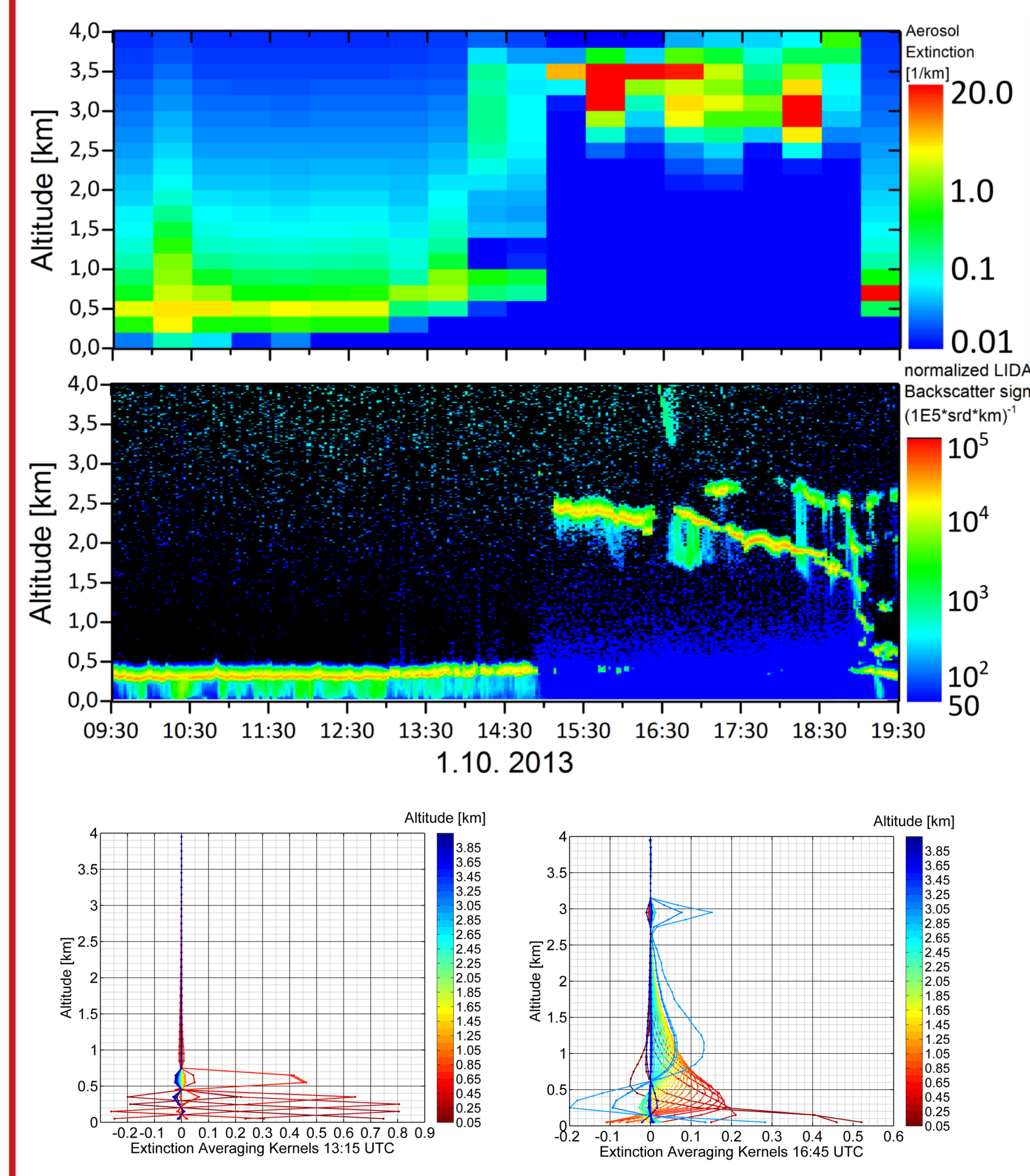
Multi-Axis DOAS

MAX-DOAS is a passive measurement configuration that uses scattered sunlight as light source. It measures slant column densities (SCDs) i.e. concentrations integrated along the light path. By scanning several elevation angles, vertical profiles of absorbing trace gases and aerosols for heights up to several kilometers can be retrieved using radiative transfer models and optimal estimation algorithms[e.g.6].

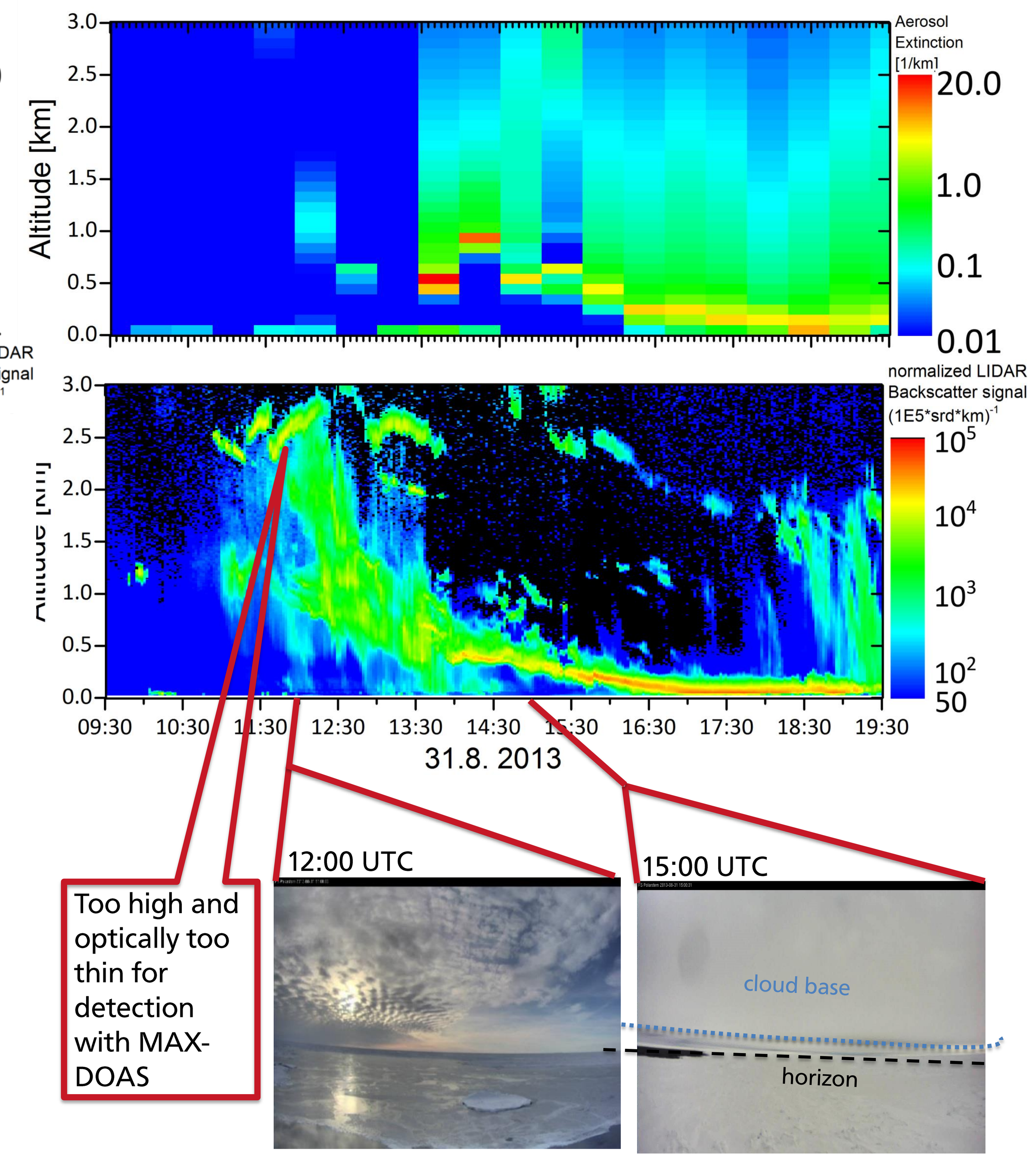
Comparison of retrieved extinction profiles with high resolution ceilometer data

To validate the extinction profile retrieval, data of a MAX-DOAS on FS Polarstern[2] and a co-located VAISALA CL-51 Ceilometer[3] from cruise ANT XXIX-7 to the Antarctic sea ice region are used. The CL-51 is a LIDAR system operating at 910 nm. The cruise was dominated by low, optically thick clouds.

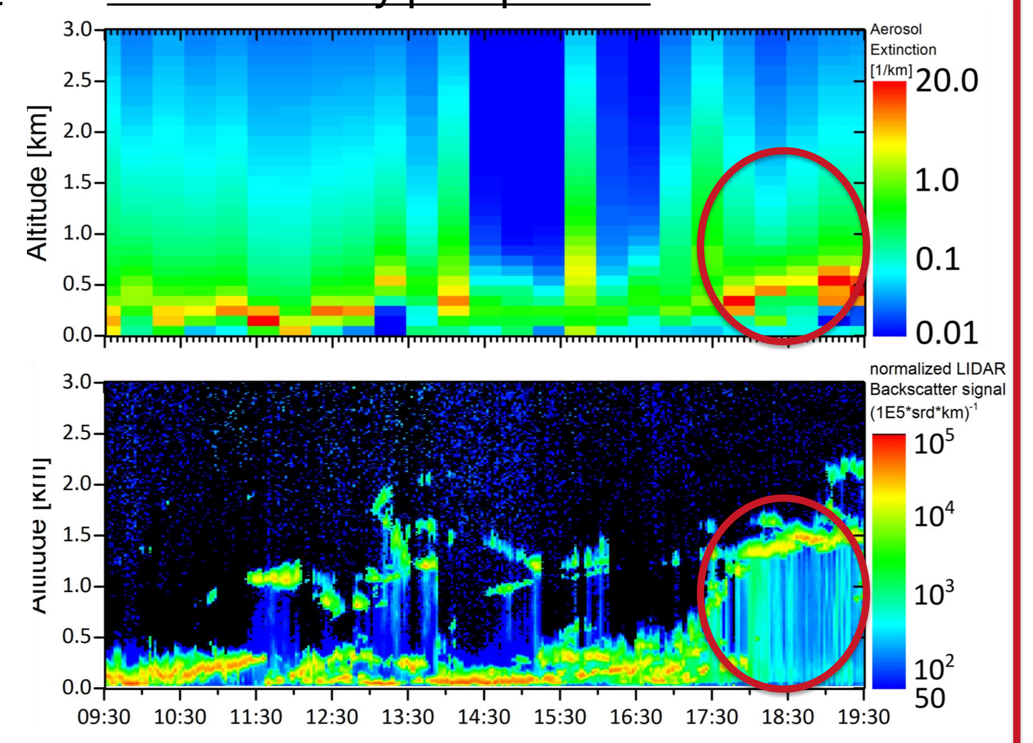
High cloud cover vs. low clod cover



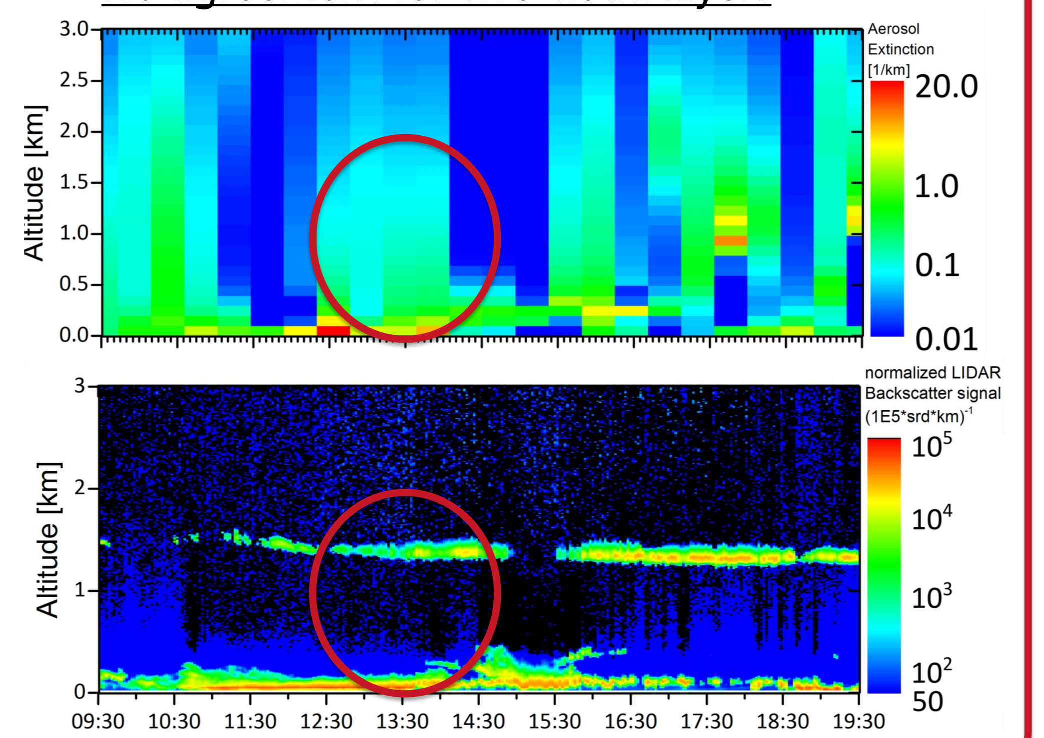
Descending cloud cover



Disturbance by precipitation



No agreement for two cloud layers

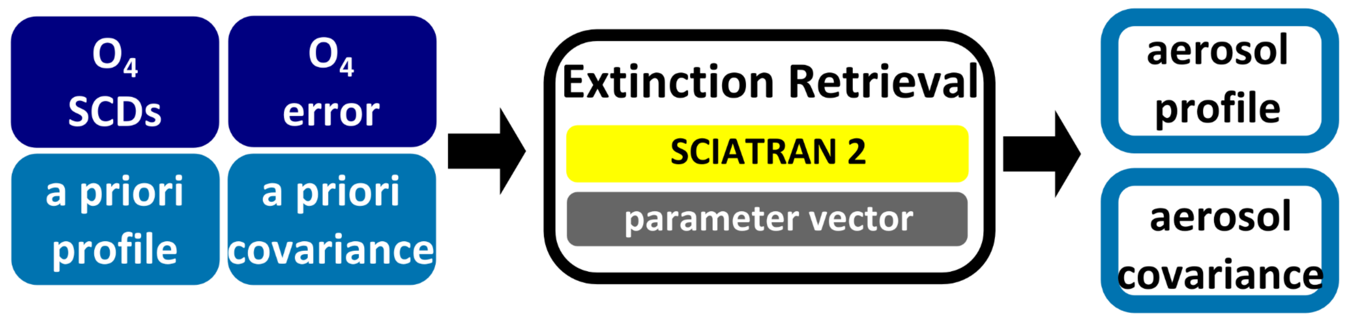


Profile retrieval by inversion

To obtain vertical extinction profiles, the state of the atmosphere $\vec{x}$ (i.e. the extinction profile) is inferred from the observable O_4 slant column densities ($\vec{y}$) using the knowledge about the functional relation between both (the radiative transfer model $F(\vec{x})$[4]).

$$\vec{y}=F(\vec{x})+\sigma_\varepsilon \Rightarrow \hat{x}$$

Since typically the information from a set of dSCDs is not sufficient to directly perform the inversion of the equation above, information from an additional a-priori profile is needed.



SCIATRAN 2: Rozanov et al. (2005)

The optimal estimation is obtained by minimizing the sum of the error-weighted differences between measured and modeled dSCDs and the actual and the a-priori profile.[6]

$$\chi^2(\vec{x})=\left[F(\vec{x})-\vec{y}\right]^T S_\varepsilon^{-1}\left[F(\vec{x})-\vec{y}\right]+\left[\vec{x}-\vec{x}_a\right]^T S_a^{-1}\left[\vec{x}-\vec{x}_a\right]$$

The retrieved state of the atmosphere therefore contains information from both measurement and a-priori estimate. The relation of both contributions in the retrieval $\hat{x}$ can be visualized with the averaging kernel matrix A:

$$\hat{x}=A\vec{x}+(I_n-A)\vec{x}_a+G\sigma_\varepsilon$$

The lines of the Averaging Kernel matrix are curves that describe from which altitudes extinction contributes to the retrieved profile in a certain altitude as well as the relative contribution of information by the measurement.
Ideally the kernels peak in their respective altitude and are zero everywhere else.

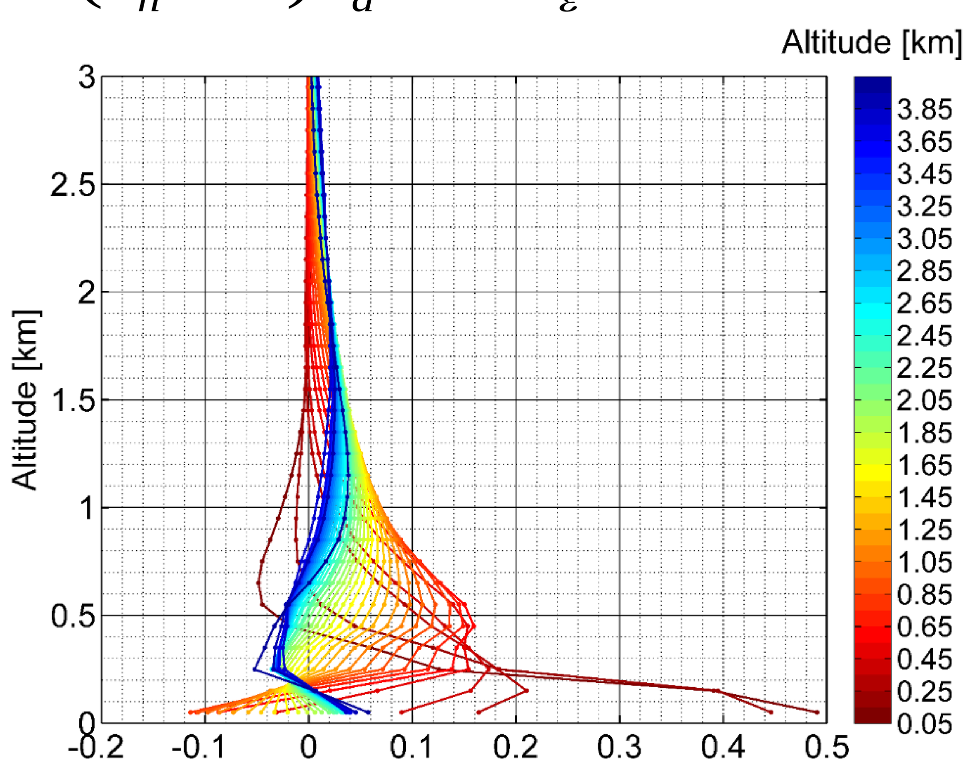


Fig.2: Typical Averaging Kernels for clear sky[2]

Conclusions

- MAX-DOAS O_4 measurements can accurately detect the cloud altitude up to 1.5km altitude. Cloud optical thickness yields realistic results but could not be validated.
- For optically thick and homogeneous cloud covers, the vertical sensibility is even extended to 2km and more because of non-linear influence of extinction on O_4 slant column densities
- Precipitation and multiple cloud layers so far lead to erroneous extinction profiles
- For homogeneous cloud cover, a trace gas retrieval using the retrieved extinction profiles is possible.
- Below homogeneous clouds, ground-based MAX-DOAS measurements are very sensitive and have a higher vertical resolution than under clear sky conditions.

References

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