Global stratospheric aerosol extinction profile retrievals from SCIAMACHY limb radiance: algorithm description and validation

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This presentation participates in the student award contest

Florian Ernst[1], Christian v. Savigny[1,2], Alexei Rozanov[1], Vladimir Rozanov[1],
Kai-Uwe Eichmann, Lena A. Brinkhoff, Heinrich Bovensmann[1], John P. Burrows[1]

[1]Institute of Environmental Physics/Remote Sensing, University of Bremen, Bremen, Germany
[2]now at: Institute of Physics, Ernst-Moritz-Arndt-University of Greifswald, Greifswald, Germany

Universität Bremen

Introduction

Stratospheric aerosols significantly influence the radiative balance of the Earth and interact in stratospheric chemistry. Scattering of sunlight and influencing the cloud formation in the upper troposphere lead to a cooling effect of different magnitude under undisturbed background conditions and periods of volcanically enhanced aerosol load. Furthermore, stratospheric aerosols play an important role in stratospheric chemistry, especially ozone depletion.

Continuous global observations of stratospheric aerosols are essential for monitoring stratospheric aerosols. These observations can only be provided by satellite measurements.

Limb observations of the scattered solar radiation combine high vertical resolution with near-global coverage, but require sophisticated radiative transfer modelling to perform the retrieval. The results can be validated with more accurate, but sparser occultation data sets.

SCIAMACHY, the Scanning Imaging Absorption SpectroMeter for Atmospheric Chartography on ESA's Envisat spacecraft is one such instrument employing the limb-scatter observation geometry. It provided broadband limb radiance measurements from 2002-2012 covering a period of undisturbed background stratospheric aerosol conditions in the first years of its lifetime and several volcanic eruptions with stratospheric impact from 2005 onwards. Thus, its comprehensive data set offers the rare possibility to investigate stratospheric aerosols under changing aerosol loads.

Goal of this work is to employ limb-scatter measurements with the SCIAMACHY instrument to retrieve stratospheric aerosol extinction profiles that form a valuable data set with global coverage on a daily basis.

Comparison with co-located SAGE II data

SAGE II:
- Sun occultation instrument, 1984 – 2005
- Measures aerosol extinction at 4 wavelengths, we are comparing to 525 nm.
- The data set is considered to be one of the stratospheric aerosol data sets with the highest accuracy.

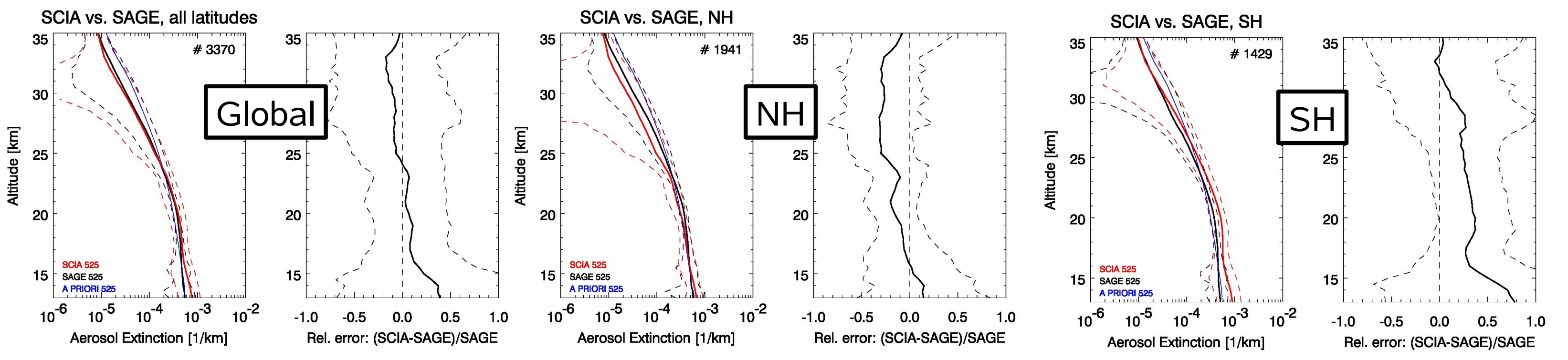
Comparison SCIAMACHY – SAGE II at collocated measuring points:
- Collocation criteria: spatial difference < 500 km and temporal difference < 6h
- data with SZA@TP > 87° filtered out
- overlap between SCIAMACHY and SAGE II: 01/01/2003 – 08/17/2005
- approx. 3500 collocations

The retrieved SCIAMACHY aerosol extinction is interpolated to 525 nm with a constant Ångstrøm exponent of 1.43.

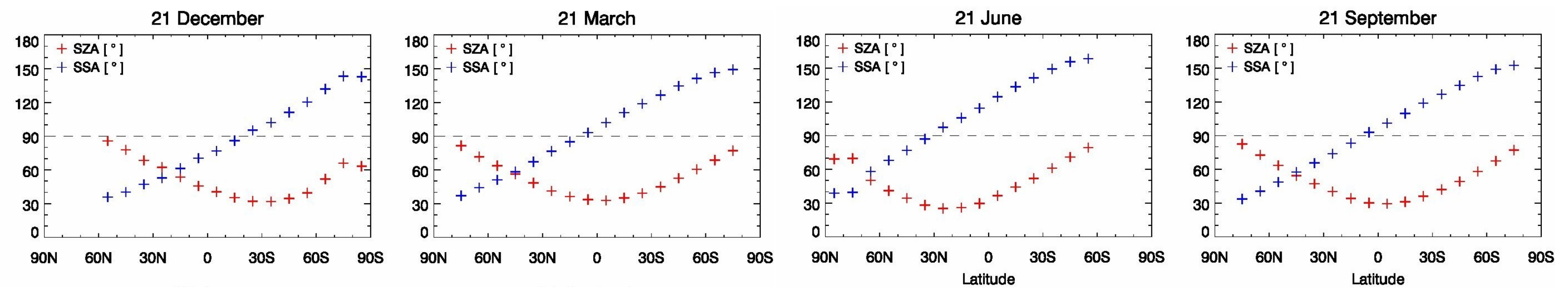
Retrieval version 1.0: Henyey-Greenstein phase function

Henyey-Greenstein approximation: $P(\Theta) = \frac{1}{4\pi} \frac{(1-g^2)}{(1+g^2-2g\cos\Theta)^{3/2}}$

Asymmetry parameter:
g (470nm) = 0.712
g (750nm) = 0.655



Good agreement in the global average, but large interhemispheric difference
→ HG approximation inappropriate for SCIAMACHY scattering angles (25° < SSA < 140°)



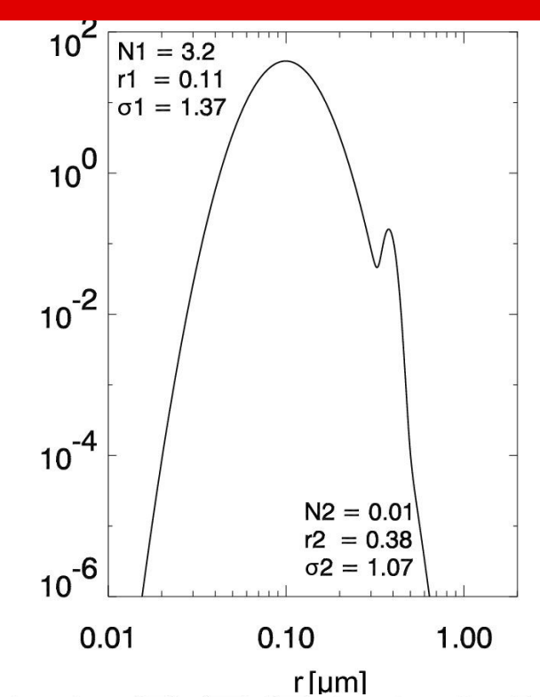
→ Solar zenith angle (SZA) and scattering angle (SSA) depend strongly on the latitude

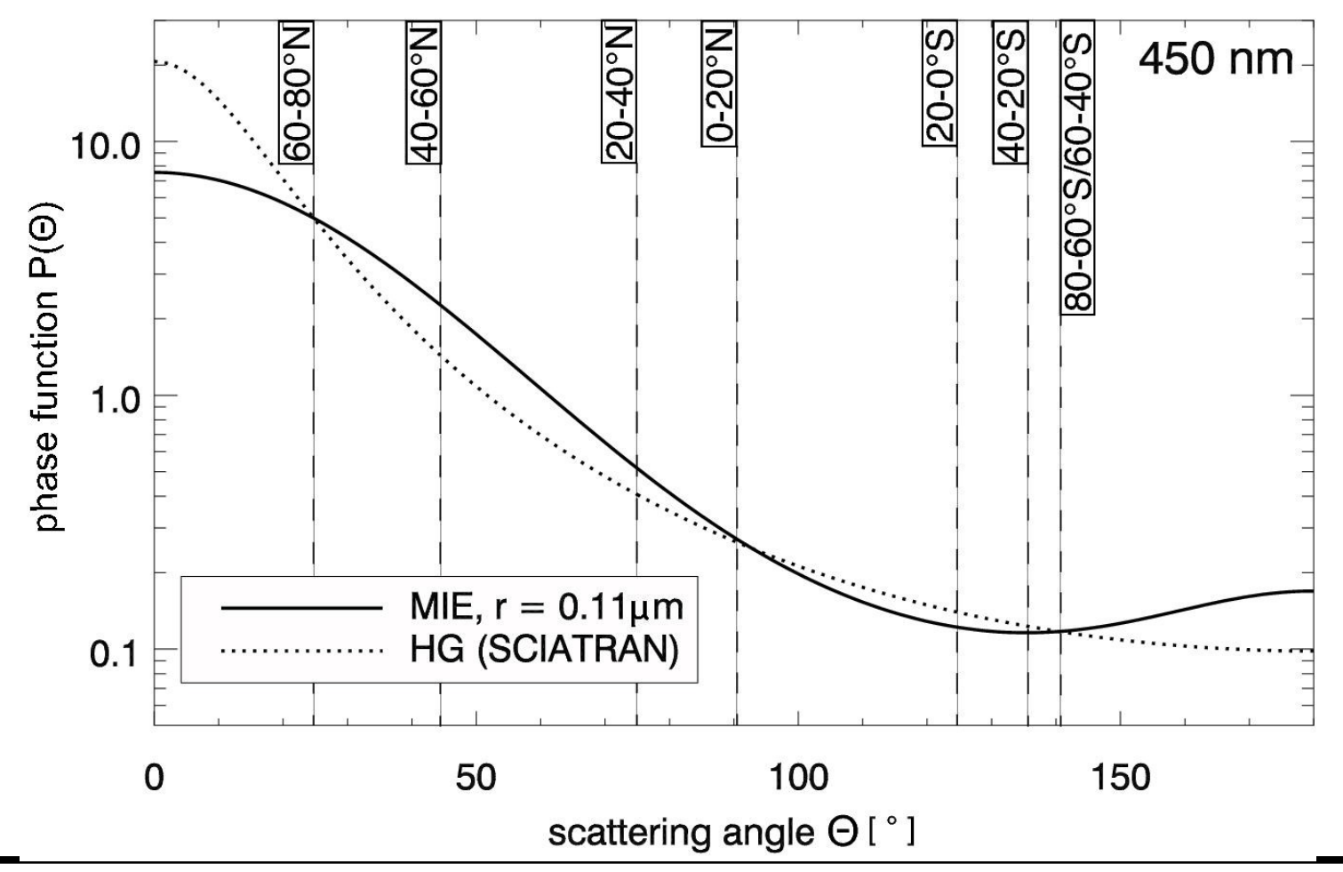
Retrieval version 1.1: Mie phase function

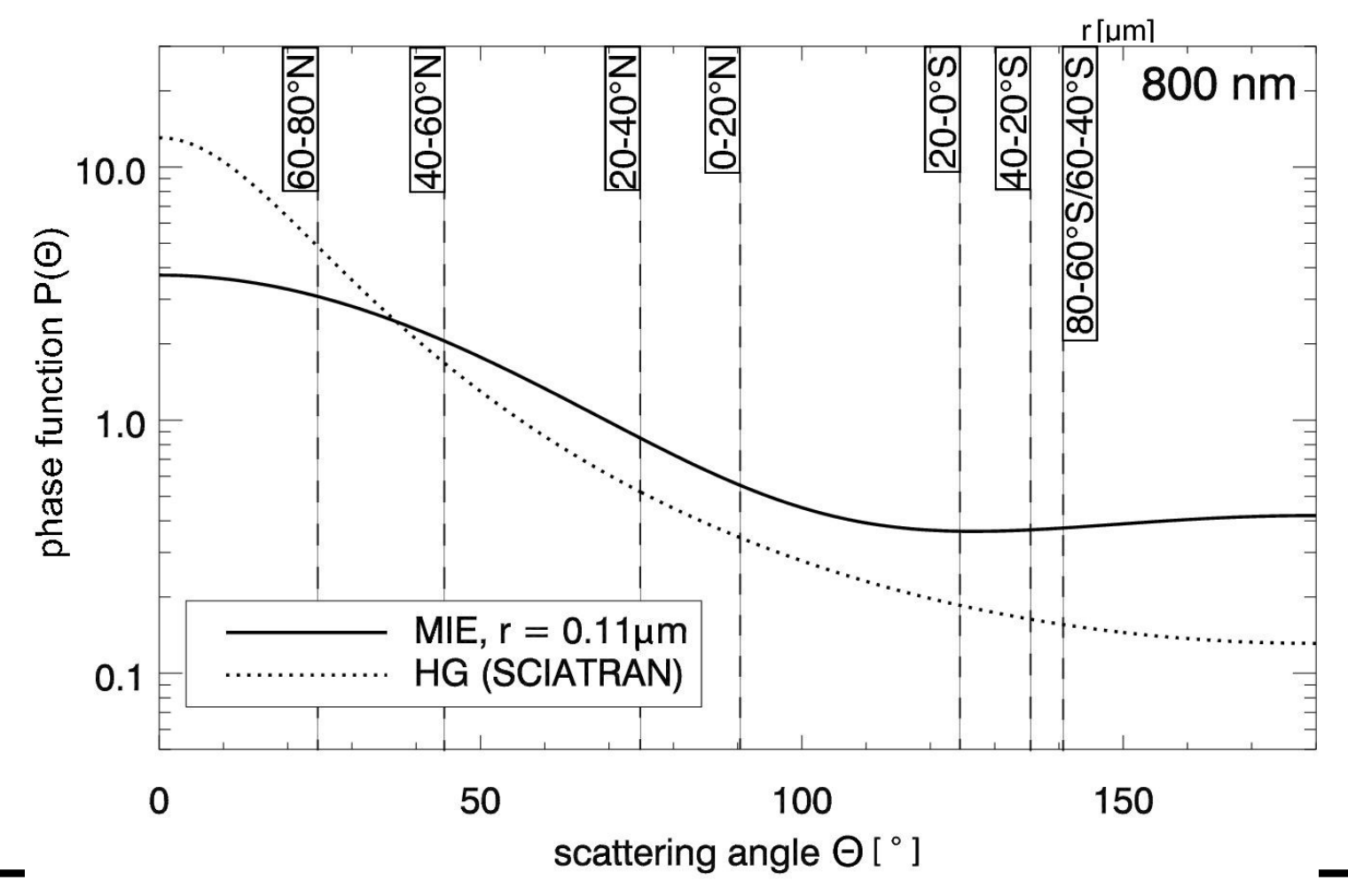
Particle size distribution above Laramie, Wyoming, USA (41°N);
in situ measurements by *[Deshler, 2003]* for background aerosols, 06.05.2006:
Bimodal lognormal distribution
we use the small mode as monomodal distribution:

Median radius r = 0.11 µm, distribution width σ = 1.37

→ used to calculate Mie phases function for two wavelengths:







Summary

Retrieval version 1.0: good agreement with SAGE II data in the global average
- 20° latitude bins: **systematic interhemispheric differences** with values of in general around 20 % to up to 50 %
- underestimation in the northern hemisphere (~20%), overestimation in the southern hemisphere (~30%, max. 60%).

Retrieval version 1.1: significant reduction of the interhemispheric difference.
- SH: difference in the southern hemisphere was reduced to values of typically 0–15 % (15-33 km)
- NH: bias remained in the northern hemisphere in comparison with SAGE II measurements.

For more information incl. a climatological interpretation of the complete SCIAMACHY stratospheric aerosol extinction data set see talk given by **Lena A. Brinkhoff: *Retrieval and variability of stratospheric aerosols from SCIAMACHY limb-scatter observations*, Wednesday 9:20!**

Retrieval scheme

Non-linear inverse problem: Obtaining stratospheric aerosol extinction coefficients out of SCIAMACHY limb radiance profiles

Construction of the measurement vector *[Bourassa et al., 2007];*
Starting point: measured or simulated SCIAMACHY radiance profiles at 2 wavelengths, 470 and 750 nm (weak atmospheric absorption)

Step 1: Tangent height normalization: $I_N^{\lambda}(TH) = I^{\lambda}(TH)/I^{\lambda}(TH_{ref})$ TH_{ref} = 35 km (aerosols below, staylight above)

Assumption: fraction of ground-reflected sunlight in the limb radiance is similar at all tangent heights (including TH_{ref})

Advantages: reduction in albedo dependence, absolute calibration not required

Step 2: Wavelength pairing: $y(TH) = \ln\left(\frac{I_N^{\lambda_l}(TH)}{I_N^{\lambda_s}(TH)}\right)$ λ_l = 750 nm, λ_s = 470 nm

Rayleigh scattering ~ λ^{-4}, Mie scattering (spherical aerosols) > λ^{-4} → Color-index-approach λ_l/λ_s amplifies the aerosol signal
Improves the linearity of the inverse problem → smaller linearization errors.

Modified Optimal Estimation Method (starting with [*Rodgers, 2000]*:

Basic equation: $\mathbf{y} = \mathbf{f}(\mathbf{x}) + \epsilon$

y = normalized and paired SCIAMACHY limb radiances („measurement vector“)
x = desired aerosol extinction profile („state vector“) (j components)

Non-linear basic equation: $\hat{\mathbf{y}} = \mathbf{K}\hat{\mathbf{x}} + \epsilon$ with $\hat{\mathbf{y}} = \mathbf{y} - \mathbf{y}_a$ $\hat{x}_j = (x_j - x_{a_j})/x_{a_j}$

Iterative solution: using x_{n-1} instead of x_a in each iterative step (important difference to OEM!)

$$\mathbf{x}^* = (\mathbf{K}_i^T \mathbf{S}_y^{-1} \mathbf{K}_i + \mathbf{S}_a^{-1})^{-1} \mathbf{K}_i^T \mathbf{S}_y^{-1} (\mathbf{y} - \mathbf{y}_i) \quad \text{with} \quad x_j^* = (x_{i+1_j} - x_{i_j})/x_{i_j}$$

$\mathbf{x_a}$ = a priori aerosol extinction
$\mathbf{y_a} = \mathbf{Kx_a}$
K = weighting function matrix
$\mathbf{S_a}$ = a prioi covariance matrix
$\mathbf{S_y}$ = noise covarinace matrix

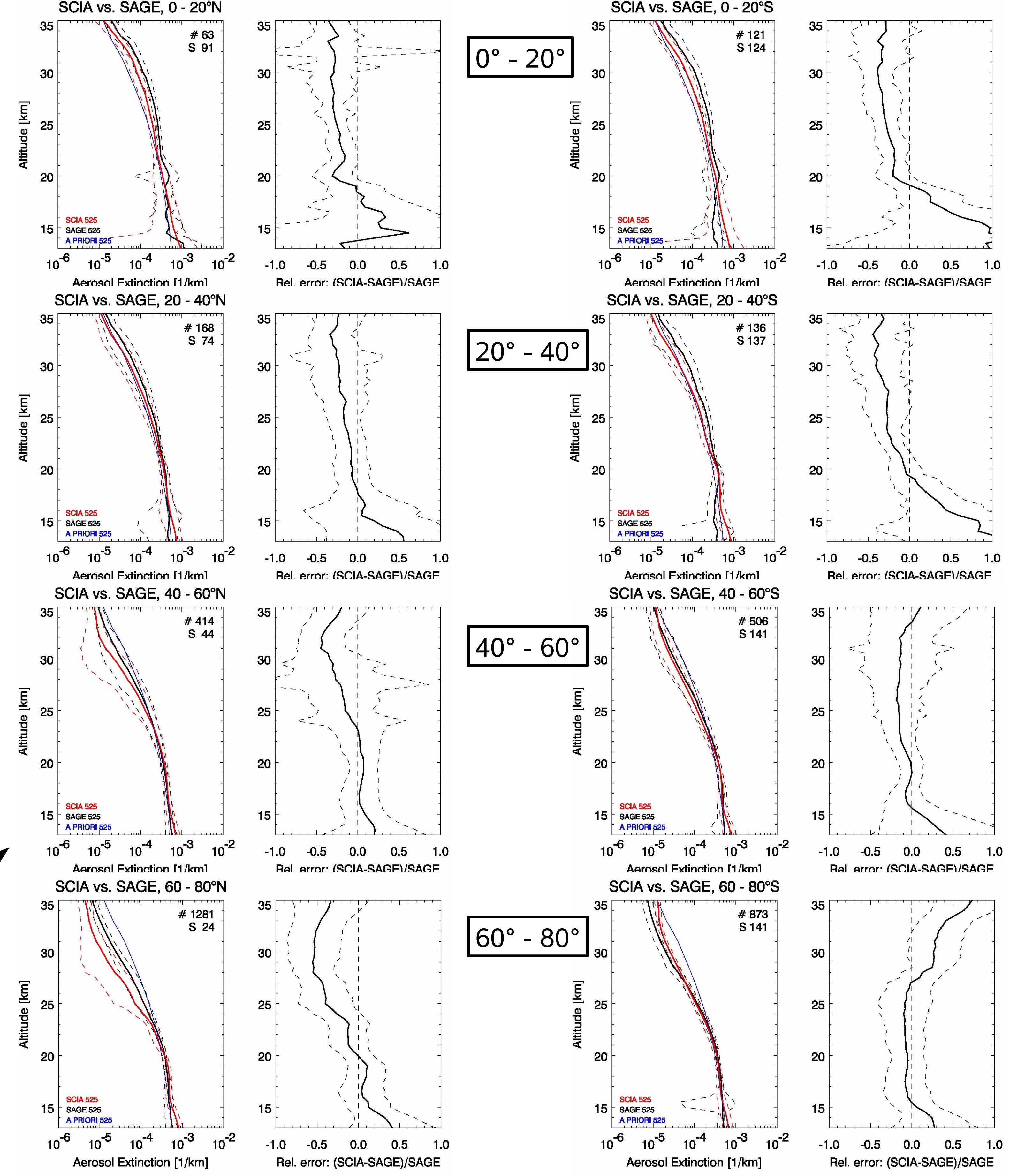
Advantage: more robust against bad a priori vs. **disadvantage: information from a priori strongly reduced**

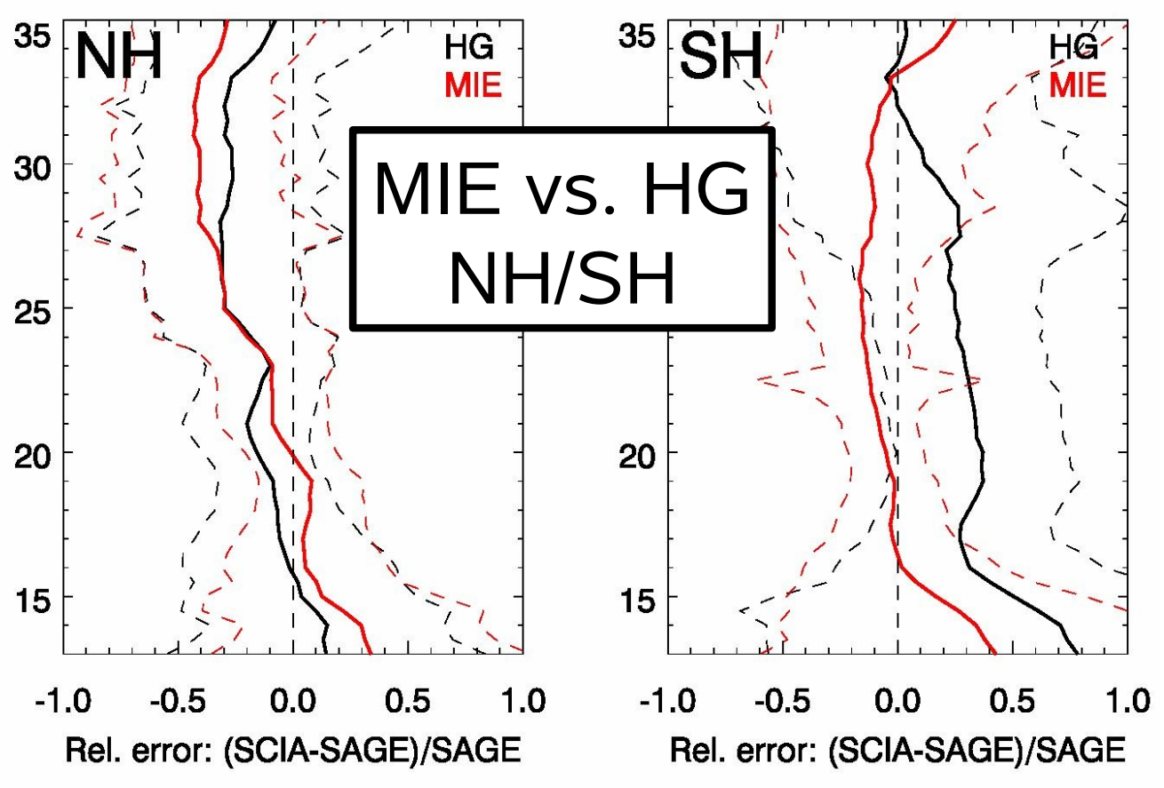
Radiative transfer model and retrieval code SCIATRAN 3.1 *[Rozanov et al., 2013]* is used to apply the scheme to the SCIAMACHY data

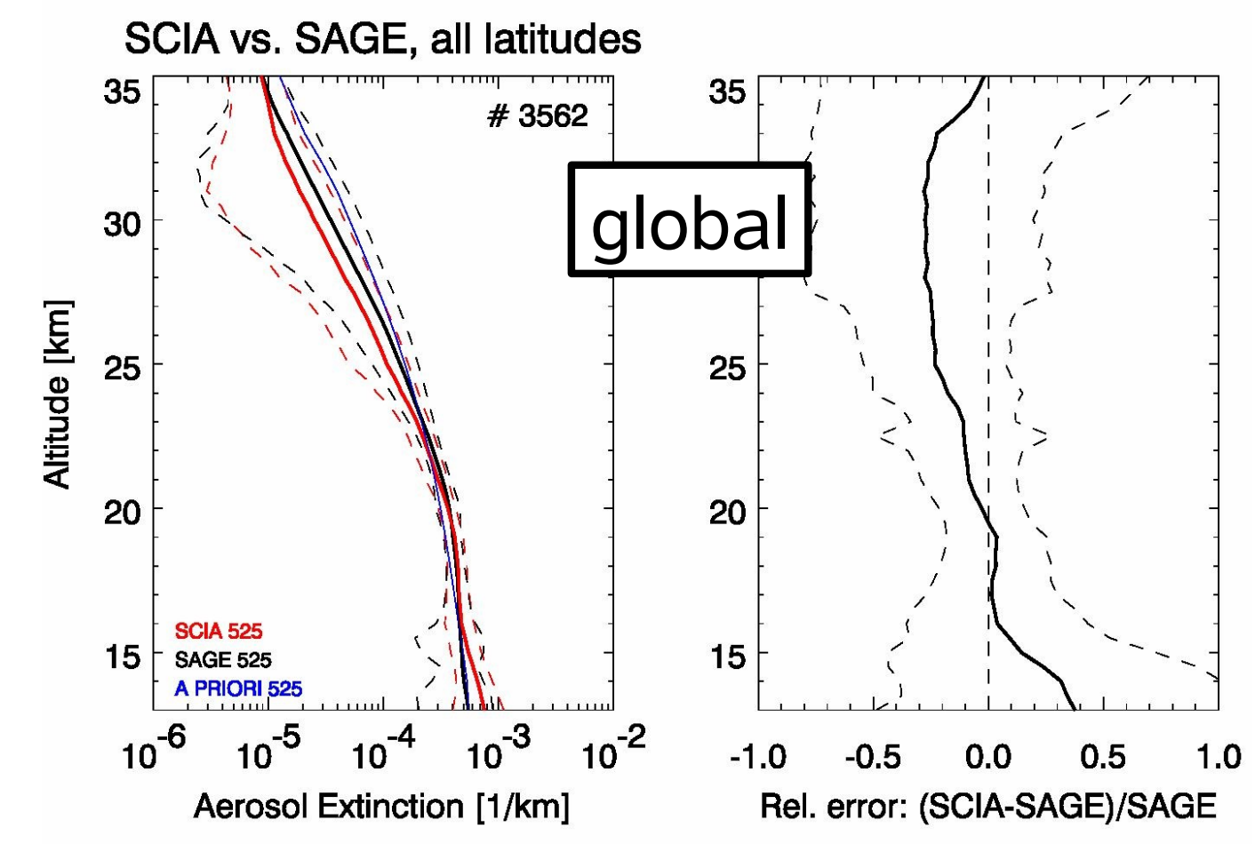
Mie phase function, 20° latitude bins

Northern Hemisphere

Southern Hemisphere







Selected references:
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Rodgers, C. D.: *Inverse Methods for Atmospheric Sounding: Theory and Practice*, World Scientific, Singapore, 2000.
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