Particle size distribution of stratospheric aerosols: from SCIAMACHY to ALTIUS

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Motivation

Stratospheric aerosols

Radiative forcing

Climate change

Radiative forcing is dependent not only on the amount of the aerosol particles but also on their size distribution
Aerosol particle size distribution (PSD)

Log-normal distribution:

\[ n(r) = \frac{N}{r \sqrt{2 \pi \ln(\sigma)}} \exp\left( - \frac{(\ln(r) - \ln(R_{med}))^2}{2(\ln(\sigma))^2} \right) \]

Parameter:

- **Particle number density**: \( N \)
- **Mode radius**:
  \[ R_{mod} = R_{med} e^{-\left(\ln(\sigma)\right)^2} \]
- **Standard deviation**:
  \[ \text{Std} = \sqrt{R_{med}^2 e^{\sigma} (e^{\sigma} - 1)} \]
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Limb observations from SCIAMACHY and ALTIUS

SCIAMACHY (08.2002 – 04.2012)
- Sun-synchronous orbit, ~800 km
- Nadir, limb, solar and lunar occultation
- Spectral mapping/spatial scanning
- 214 – 2386 nm spectral range
- 0.22 – 1.48 nm spectral resolution
- -3 – 100 km Vertical range
- 3.3/2.5 km vertical sampling/field of view
- 960/240 km horizontal swath/resolution

ALTIUS (2022 - )
- Sun-synchronous orbit, ~700 km
- Limb, solar/lunar/planet/stellar occultation
- Spectral scanning/spatial mapping
- 250 – 1800 nm spectral range
- 2.5 – 10 nm spectral resolution
- 0 – 100 km Vertical range
- 1 km vertical sampling/field of view
- 100/1 km horizontal swath/resolution
Spectral information

Red: Optical depth of gaseous absorbers at 21.6 km tangent height
Blue: SCIAMACHY wavelengths
Cyan: possible ALTUIS wavelengths
Sensitivity studies
Weighting functions: spectral behavior

\[
W = \frac{\partial \ln I_\lambda(h_t)}{\partial x(h)}
\]

Tangent height: \( h_t = 21 \, km \)

Altitude: \( h = 21 \, km \)

\( x \): 
- Mode radius, \( r_{\text{mod}} \)
- Distribution width parameter, \( \sigma \)
- Particle number density, \( N \)
Weighting functions: spectral behavior

The weighting functions look similar but have different curvature.

Are they linearly independent?

Is it possible to retrieve 3 parameter together?
Weighting functions: spectral behavior

![Graph showing weighting functions](image)

Weighting functions are plotted against wavelength in nanometers (nm). The graphs illustrate the spectral behavior of different weighting functions, including N, r_mod, and σ. The differences in the logarithmic weighting functions are also depicted, with ALTIUS represented separately.
Weighting functions: spectral behavior

- **Logarithmic weighting functions**
  - N
  - $r_{\text{mod}}$
  - $\sigma$

- **Differences in the logarithmic weighting functions**
  - ALTIUS
  - SCIAMACHY

**Wavelength, nm**

- 800
- 1000
- 1200
- 1400
- 1600

- **Logarithmic weighting functions** range from 0.6 to 1.4
- **Differences in the logarithmic weighting functions** range from -0.04 to 0.04
Weighting functions: spectral behavior

[Graph showing spectral behavior of weighting functions, with plots for different functions and wavelengths.]

Logarithmic weighting functions

Differences in the logarithmic weighting functions

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SCIAMACHY
Sensitivity to the aerosol parameters

\[ \ln \left( \frac{I}{I_0} \right) \]

Wavelength, nm

\[ R_{mod} = 0.08 \mu m, \sigma = 1.37 \]

25 km tangent height
Sensitivity to the aerosol parameters

25 km tangent height

\[ \ln\left(\frac{I}{I_0}\right) \]

Wavelength, nm

\[ R_{mod}=0.08 \mu m, \sigma=1.37 \]

\[ \sigma \text{ variation } 1.1 \div 2.0 \]
Sensitivity to the aerosol parameters

\[ \ln \left( \frac{I}{I_0} \right) \]

-5

-6

-7

-8

-9

Wavelength, nm

\( R_{mod} = 0.08 \ \mu m, \sigma = 1.37 \)

\( \sigma \) variation 1.1 ÷ 2.0

\( R_{mod} \) variation 0.05 ÷ 0.15 \( \mu m \)

25 km tangent height
Sensitivity to the aerosol parameters

Only $R_{\text{mod}}$ and $\sigma$ are currently retrieved

25 km tangent height

$\ln(I/I_0)$ vs Wavelength, nm

- $R_{\text{mod}} = 0.08 \ \mu\text{m}, \sigma = 1.37$
- $R_{\text{mod}}$ variation $0.05 \div 0.15 \ \mu\text{m}$
- $\sigma$ variation $1.1 \div 2.0$
- N variation $1.0 \div 2.0$
Accuracy of the mode radius retrieval

SCIAMACHY

ALTIUS

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Accuracy of the distribution width retrieval

SCIAMACHY

ALTIUS

altitude, km

relative error, %

background: $R_{mod}, \sigma$

volcanic: $R_{mod}, \sigma$

volcanic (2N): $R_{mod}, \sigma, N$
SCIAMACHY results

- Only mode radius and distribution width are retrieved so far
- Retrieval are done only in tropics
- Only completely cloud free scenes are processed
Aerosol PSD: tropical time series (20ºS – 20ºN)
Aerosol PSD: tropical time series ($20^\circ$S – $20^\circ$N)
Aerosol PSD: tropical time series (20°S – 20°N)

Mode radius anomalies

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SCIAMACHY
Aerosol PSD: tropical time series (20°S – 20°N)
Evolution of the aerosol particle size distribution

Light blue: background aerosol loading
Red: volcanic aerosols
Purple: relaxation period

25 km tangent height

December 2004
Evolution of the aerosol particle size distribution

- Light blue: background aerosol loading
- Red: volcanic aerosols
- Purple: relaxation period

25 km tangent height

- December 2004
  - 28.01.2005 Manam
    - 4°S, 145°E

- May 2005

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SCIAMACHY
Evolution of the aerosol particle size distribution

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May 2005
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25 km tangent height

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February 2006
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25 km tangent height

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- May 2005
- November 2005
- February 2006
  - 20.05.2006 Soufriere Hills
  - 17°N, 62°W
  - 11.08.2006 Tavurvur
  - 4°S, 152°E

- September 2006

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SCIAMACHY
Evolution of the aerosol particle size distribution

- **25 km tangent height**
- **Light blue**: background aerosol loading
- **Red**: volcanic aerosols
- **Purple**: relaxation period

- **December 2004**: 28.01.2005 Manam, 4°S, 145°E
- **May 2005**
- **November 2005**
- **February 2006**: 20.05.2006 Soufriere Hills, 17°N, 62°W
- **September 2006**: 11.08.2006 Tavurvur, 4°S, 152°E
- **March 2007**
Evolution of the aerosol particle size distribution

Light blue: background aerosol loading
Red: volcanic aerosols
Purple: relaxation period

25 km tangent height

December 2004
28.01.2005 Manam
4°S, 145°E

May 2005

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February 2006
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4°S, 152°E

September 2006

March 2007

November 2007
Summary

SCIAMACHY technical aspects

- Retrieval of two parameters of the aerosol PSD is successfully implemented
- Accuracy of about 5% is reached if the number density is known
- 10-20% uncertainty due to unknown aerosol particle number density in the volcanically active periods, additional instigations are needed to mitigate the effect

SCIAMACHY results

- Clear signatures of the volcanic eruptions are identified in the PSD parameters
- Single volcanic eruptions usually result in a shift of the distribution to larger radii, not affecting much the distribution width
- Overlapping eruptions result in a clear increase of the distribution width
- The relaxation period is about 1 year

ALTIUS

- SCIAMACHY retrieval approach can be transferred to ALTIUS
- Better accuracy than for SCIAMACHY is expected (because of better SNR)
- Spectral range around 870 nm is needed to retrieve three PSD parameters