2D Tomography for SCIAMACHY
Limb Measurements of Scattered Sunlight


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Limb measurement mode

- Very slant path of line of sight through atmosphere (up to ~113 km/1km close to TP)
- High extinction along LOS up to the middle stratosphere
- Horizontally non-homogeneous distribution of atmospheric parameters

SCIAMACHY:

- Tangent height range: 0 to 100 km
- Scan width 240 km x 4 pixels
- Tangent height step size: ~3.3 km
- Vertical FOV: ~2.6 km
Retrieval algorithm - Two step approach

Measured spectra

Differential optical absorption spectroscopy (DOAS)

Slant column densities

Inversion (optimal estimation or least squares approach)

Concentration profiles

Retrieval algorithm - Two step approach

Differential optical absorption spectroscopy (DOAS)

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Concentration profiles
Validation and Verification
- with balloon measurements

![Graph showing NO₂ and BrO withSCIAMACHY and balloon measurements, Kiruna 23 March 2003 orbit 5545](image)

- with models

![Graph showing NO₂ with SCIAMACHY and EMAC, 15 Sept 2007](image)

Jöckel et al., Butz et al., Dorf et al.
Validation and Verification

- with balloon measurements

NO$_2$

Kiruna
23 March 2003
orbit 5545

SCIAMACHY balloon

BrO

Kiruna
23 March 2003
orbit 5545

- with models

SCIAMACHY

EMAC

Butz et al., Dorf et al.

Poster by Kühl et al.

Jöckel et al.

Poster by Kühl et al.
Horizontal gradients along the orbit

RTM McArtim (Deutschmann, 2009)
Tomographic 2D retrieval

- Information (SCDs) of different limb scanning sequences can be combined in one inversion if the sensitivity regions overlap.

- Small distance between the scanning sequences (the areas from which light is contributing to the measurement is partially overlapping).

- Small temporal variability of parameters influencing photochemistry in the atmosphere.

- Radiative transfer modeling (RTM) resolving spatial sensitivity of measurements not only vertically but also horizontally (2D box AMFs).
Retrieval algorithm - Two step approach

**Measured spectra**

- Differential optical absorption spectroscopy
- Slant column densities of scanning sequence
- Inversion (optimal estimation or least squares approach)
- Concentration profiles

**1D**

- 1D box air mass factors (RTM)
- $SCD_g = h \sum_{b_{alt}} AMF_{g,b_{alt}} n_{alt}$

**2D**

- Differential optical absorption spectroscopy
- Slant column densities of all scanning sequences of one orbit
- Inversion (optimal estimation or least squares approach)
- 2D box air mass factors (RTM)
- $SCD_g = h \sum_{b_{air lat}} AMF_{g,b_{air lat}} n_{alt lat}$

**2D concentration field**
Consideration of horizontal gradients at polar vortex boundary

OCIO and NO₂ vertical profile retrieval (1D and 2D) for 20 January 2005.

Puķīte et al., 2008
Consideration of horizontal gradients at polar vortex boundary

OCIO and NO$_2$ vertical profile retrieval (1D and 2D) for 20 January 2005.

Puķīte et al., 2008
Sensitivity studies OCIO

Gradient from $3.5 \times 10^7 - 0 \text{ cm}^{-3}$ from $71^\circ - 61.5^\circ$ lat. 
$\sigma=4 \text{ km}$

true on retrieval grid
Sensitivity studies OCIO

Gradient from $3.5 \times 10^7 - 0 \text{ cm}^{-3}$

The effect: $0.5...1.2 \times 10^7 \text{ cm}^{-3}$

Gradient from $3.5 \times 10^7 - 0 \text{ cm}^{-3}$

from $71^\circ - 61.5^\circ \text{ lat.}$

$\sigma = 4 \text{ km}$

The effect: $0.37 \times 10^7 \text{ cm}^{-3}/\text{o lat}$

Sensitivity studies OClO
Operational change request nr 38 (Puķīte et al.) was accepted by ESA and performed on 14.12.2008 for 7 limb orbits (35499 - 35505) operating exclusively in limb mode i.e. without nadir measurements between

“normal” orbit

“full limb” orbit
NO$_2$, orbit 35499, on 14.12.2008
Mean for full limb orbits (descending part)

Typical gradients $0.5 \ldots 1 \times 10^8$ (molec./cm$^3$)/deg

Typical effect $\ldots 2 \times 10^8$ (molec./cm$^3$) $\rightarrow$ 10...20 %
Simulation studies

Effect of gradient strength on the error

Typical gradients $0.5 \ldots 1 \times 10^8 \text{ (molec./cm}^3)/\text{deg}$ for NO$_2$

Typical effect $\ldots 2 \times 10^8 \text{ (molec./cm}^3) \rightarrow 10\ldots20 \%$
Measurements on a different grid – distances between scanning sequences changed

Distance ~6.6°
(very similar to normal SCIAMACHY operation mode)

Gradient $0.5 \times 10^8$ cm$^{-3}$/°lat

Distance ~3.3°
(like in the full limb mode)

Distance ~1.7°

Distance ~0.8°

The best distance for UV/VIS measurements
Correction for parts of orbit with lower resolution (nadir states in between):

- test it for "full limb" orbits skipping every 2nd scanning sequence!
Orbit 35499

2D

2D-2D interp (even sc. sequences)

2D-2D interp₄₅ (odd sc. sequences)

2D-1D
Conclusions

• The tomographic 2D approach improves the retrieval for cases with large horizontal gradients.

• The 2D approach was successfully applied for the “full limb” orbits for SZA<90° for retrieval of NO₂ on 14.12.2008.

• The 2D method improves the retrieval at 20 km and below with respect to 1D method by ~10...20% of peak value of NO₂ (especially at southern tropics and between southern mid-latitudes and polar regions in December with gradient 0.5...1 x10⁸ molec.cm⁻³/1°).

• Spatial distance of ~2...3° (a bit smaller than the SCIAMACHY full limb mode) between scanning sequences allows to consider horizontal gradients.

• Horizontal gradients can be considered to some extent also by interpolation approach for “normal” orbits by assuming a step in change of concentration between two scanning sequences.

• Implementation of the full limb orbits on a monthly scale would allow further investigation of the horizontal gradient effect, especially for polar winter and spring.

• Horizontal gradient effect was investigated for NO₂ and OCIO but could be very important also for BrO and especially for ozone where very high accuracy is required.