CSIAMACHY limb measurements in the UV/Vis spectral region: first results

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Abstract

Stratospheric density profile measurements of ozone and nitrogen dioxide derived from limb scattered radiance spectra measurements of the SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY (SCIAMACHY) are presented in this paper. SCIAMACHY is part of the ENVISAT satellite instrumentation, which has been successfully launched in March 2002. SCIAMACHY determines both the total amount and vertical density distributions of a large number of atmospheric constituents by measuring the Earthshine radiance, simultaneously from the ultraviolet (UV) to the near infrared (NIR), in the three viewing geometries nadir, limb, and occultation. The results of the trace gas retrievals of ozone and nitrogen dioxide are compared with nearby POAM III measurements as a first step of verification.

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1. Introduction

The SCanning Imaging Absorption SpectroMeter for Atmospheric CHartographY (SCIAMACHY) instrument is a space-based spectrometer (Burrows and Chance, 1991) launched on board ENVironmental SATellite (ENVISAT) in March 2002 (see e.g. Bovensmann et al., 1999). SCIAMACHY employs three distinct viewing modes during each orbit cycle to measure the sun light scattered and absorbed by the Earth’s atmosphere: nadir, limb, and occultation.

The limb viewing mode of SCIAMACHY is used to overcome the limited vertical resolution of retrieved trace gas profiles from nadir viewing spectrometers like the Global Ozone Monitoring Experiment (GOME) (Burrows et al., 1999; Hoogen et al., 1999) and the limited horizontal coverage of occultation experiments like HALogen Occultation Experiment (HALOE) (Russell et al., 1993), Polar Ozone and Aerosol Measurement (POAM) (Lucke et al., 1999), and Stratospheric Aerosols and Gas Experiment (SAGE) (McCormick et al., 1989). The limb scatter technique has previously been used by the Limb Ozone Retrieval Experiment/Shuttle Ozone Limb Sounding Experiment (LORE/SOLSE) instruments flown in 1997 on NASA’s space shuttle mission STS-87 (Flittner et al., 2000). It has also been applied to the measurements of the Optical Spectrograph and Infrared Imager System (OSIRIS) (Llewellyn et al., 1997) aboard the Odin satellite (Murtagh et al., 2002) launched in February 2001.

This paper, presents first results of both ozone and nitrogen dioxide density profiles retrieved from SCIAMACHY limb scatter measurements. To verify the limb retrieval algorithm, first comparisons with trace gas profiles of the POAM III occultation instrument on board the French SPOT-4 satellite (Lucke et al., 1999) were made.
2. The SCIAMACHY instrument

SCIAMACHY is a passive remote-sensing spectrometer detecting light in the wavelength range from the ultraviolet (240 nm) to the near infrared (2380 nm) with moderate resolution (0.24–1.48 nm). This spectral range is divided into eight channels, each science channel comprises 1024 pixel. Thus approximately 8000 spectral points are recorded simultaneously. For most of the orbit, SCIAMACHY makes alternating nadir and limb measurements.

In limb viewing mode, SCIAMACHY is looking forward into the flight direction, scanning the atmosphere horizontally and vertically. The instantaneous field-of-view (IFOV) for the limb mode is 0.045° vertically and 1.8° horizontally, corresponding to a geometrical field-of-view at the tangent point of 2.6 and 110 km, respectively. One limb cycle has a total duration of 60 s. Each horizontal (azimuth) scan has a duration of 1.5 s and is divided into up to four individual scans depending on the intensity of the radiance as a function of the wavelength. Thus the spatial resolution in across track (azimuth) direction is typically 240 km, determined by the integration time. A total of 35 vertical scan steps are made. Starting at about ~3 km tangent height, the tangent height step size is typically 3.3 km. 34 horizontal scan steps up to 100 km altitude are performed and one dark signal measurement at about 150 km altitude. The horizontal scans are covering 960 km in across-track direction. The light path in along track direction is approximately 400 km. More details on the characteristics of the SCIAMACHY instrument and the data products can be found in e.g. Bovensmann et al. (1999).

3. Data and methods

For this paper, the raw level zero SCIAMACHY data were used, which is the signal (counts) integrated over the whole azimuth scan of 960 km to get a better signal-to-noise ratio. The data are divided by the integration times (s) and a preliminary dark current correction is performed by subtracting the spectrum at 150 km tangent height. To eliminate the effects of the solar Fraunhofer structure and multiplicative instrumental artifacts, the signal is divided by the spectrum at about 50 km tangent height. The polarization sensitivity of the instrument is not taken into account. The tangent height information is taken from the operational data product.

Two forward models were used to simulate the limb scattered radiances. The spherical version of SCIAMACHY on April 25, 2002 over North America to derive the vertical ozone distribution. In Fig. 1 the flight path of ENVISAT and the points of limb measurements are plotted over a total ozone map from the ERS-2 GOME.
instrument (Burrows et al., 1999), which is flying in the same orbit with a time difference of half an hour.

Ozone profiles derived from the two methods developed at the University of Bremen using two different forward models are shown in Fig. 2. The SCIAMACHY ozone number densities (cm\(^{-3}\)) as a function of altitude (km) between 10 and 40 km are also compared to the measurements of the POAM III occultation sensor. POAM III has a slightly better vertical resolution of 1–2 km in the stratosphere (Lucke et al., 1999) and is validated against ozone sondes and other satellite measurements. All three profiles agree fairly well (within 10%) taken the different vertical resolution and the differences in viewing geometry, geolocation and measurement time into account. POAM has a three times higher vertical resolution leading to more features in the profile. It also has completely different viewing angles, so even if the tangent points of both instruments are at the same place and time, they will see different air masses. The result of this effect is hard to quantify from one measurement alone and has to be studied in a comprehensive validation campaign which is beyond the scope of this paper. The integrated subcolumns between 10 and 40 km are 378 and 384 DU for SCIAMACHY and POAM, respectively. The total ozone column for the geolocation of the SCIAMACHY measurement from GOME and TOMS are 459 and 456 DU, respectively.

A latitude–altitude cross-section of the ozone density (10\(^{12}\) cm\(^{-3}\)) from 70\(^\circ\)N to 60\(^\circ\)S is shown in the upper part of Fig. 3. High values of ozone at high altitudes can be found in the tropics. Towards the high latitudes the ozone maxima decrease in altitude. In the Northern hemisphere the maximum can be found below 20 km. This corresponds to the increase in total subcolumn

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Fig. 1. Spatial distribution of GOME total ozone amounts (DU) measured on April 25, 2002 in the Northern hemisphere. Overplotted as grey boxes are the SCIAMACHY geolocations of the tangent point field of view at ground of the limb measurements for the orbit 00798. The circle and the square depicts the locations of the profiles shown in Fig. 2 from SCIAMACHY and POAM III, respectively.

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Fig. 2. Ozone number density (cm\(^{-3}\)) profile for Orbit No. 00798 on April 25, 2002. The diamonds and the quadrates depict the two retrieval methods for SCIAMACHY, while the circles depicts the POAM III measurements.
ozone from 10 to 50 km shown in the lower part of Fig. 3, where we find more than 400 DU north of 55°N. This is what can be expected for this region and part of the year (see Fig. 1).

Fig. 4 shows a comparison of NO₂ number density profiles retrieved from SCIAMACHY limb spectra (black line) measured on August 8, 2002 at 61°N, 160°W (orbit 2302, start time 21:50) to a nearby measurement made by the POAM III occultation instrument. As POAM measurements were performed during local sunset, and NO₂ has a rather strong diurnal variability, these measurements were reduced to the SCIAMACHY solar zenith angle using the SLIMCAT 1D photochemical model (Chipperfield, 1999). The reaction photolysis rates are from the JPL 2000 database (Sander et al., 2000). This was done by scaling the model NOₓ so that values at sunset correspond to the POAM measurement. However, this scaling procedure introduces an uncertainty due to an effective solar zenith angle which is assigned to the POAM measurement. Different
grey lines in the Figure show the dependence of the POAM-measurement converted to the solar zenith angle corresponding to SCIAMACHY measurement on the effective solar zenith angle assigned to the POAM measurement.

5. Conclusions

First results of the SCIAMACHY limb retrieval in the UV/Vis region for ozone and nitrogen dioxide are presented. Vertical profiles of ozone density between 10 and 50 km and of nitrogen dioxide between 10 and 40 km, both with a vertical resolution of about 3 km, have been derived. First verification of the ozone vertical profile with POAM III data shows promising results. Using a 1D photochemical model to modulate the POAM nitrogen dioxide profile for the time SCIAMACHY made the measurements, good agreement can be found. Despite problems with SCIAMACHY level 1 calibration the usage of SCIAMACHY level zero data leads to good quality in profiles when using an internal calibration procedure. We were able to retrieve ozone profiles for whole orbits.

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References


