SCIAMACHY limb spectra

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Abstract

The space-borne spectrometer SCIAMACHY aboard ESA’s Envisat satellite has been observing the Earth’s atmospheric radiance since April 2002. The instrument is recording spectra which cover the ultra-violet, visible, and near infra-red spectral regions almost continuously. The measurements are performed in three different geometries. In this article, we show for the first time limb scattering spectra which cover SCIAMACHY’s entire spectral range. The atmospheric features are separated from the solar and instrumental features by a normalization procedure. Prominent features of all three types are discussed.

Keywords: Atmospheric radiance; SCIAMACHY; Limb spectra

1. Introduction

The spectrometer SCIAMACHY (Bovensmann et al., 1999) is observing the atmosphere’s radiance in three geometries (nadir, limb and solar/lunar occultation) in the UV, visible and near IR (NIR) spectral ranges. Atmospheric parameters are determined vertically as well as horizontally resolved on a global scale from the measurements. Additionally, SCIAMACHY observes the extra-terrestrial solar irradiance.

The spectrometer incorporates eight channels, which measure mostly consecutive spectral ranges from 240 to 2380 nm. Each channel records about 1000 spectral points with a resolution of 0.25–1.5 nm. Thus a large set of atmospheric parameters including trace gas concentrations (O₃, NO₂, OCIO, BrO, CH₄, CO₂, CO, H₂O, and others), temperature, and aerosol extinction can be retrieved simultaneously. First retrieval results from limb measurements are shown in Eichmann et al. (2004).

This paper focuses on the spectra measured in limb geometry. The geometry is visualized in the Fig. 1. SCIAMACHY is recording several spectra with line of sights directed into the atmosphere above Earth’s horizon. The distance between each line of sight and the Earth’s surface is called the tangent height. Spectra are measured in dependency of tangent heights. The values typically cover the entire troposphere, stratosphere, and mesosphere. The measurements are performed on the day-side of the Earth. Thus the sun illuminates the different observed scenes from different positions in the sky.

The recorded photons are of solar origin. Since they have been scattered into the instrument’s line of sight in the atmosphere, the measurements are also called limb scattering measurements. The name emphasizes the difference to occultation measurements and limb measurements in spectral regions of lower energy, which observe the transmission and the thermal emission, respectively. The latter is negligible in SCIAMACHY’s spectral range. However, emission due to non local thermodynamic equilibrium (NLTE) in the upper atmosphere contributes significantly to some parts of the spectra.

Besides SCIAMACHY, only two other space-borne instruments have been dedicated to the observation of limb scattering spectra: the SOLSE instrument (McPeters et al., 2000), which was operated on the Space Shuttle in 1997, and OSIRIS (Llewellyn et al., 1997),
which was launched aboard the ODIN satellite in 2001. However, the ranges of their continuous spectra are limited to the UV and visible, while SCIAMACHY’s also covers the NIR.

SCIAMACHY was launched aboard ESA’s Envisat satellite on March 1, 2002. Limb spectra have been observed since the opening of the limb port on April 3. The signal to noise level of the spectra with wavelengths above 1590 nm has improved dramatically after the radiative cooler opening on April 15. Nadir measure-
ments have been available since the nadir port opening on June 20.

We present for the first time a typical sequence of limb measurements covering SCIAMACHY’s entire spectral range, i.e., 240–2380 nm.

2. Spectra

The raw data from an early limb measurement by SCIAMACHY is shown in Figs. 2–4. The measurement was obtained on April 25 near the equator above the Pacific Ocean, i.e., at about 135 °W.

The spectra were recorded for 34 tangent heights ranging from −2 to 97 km with 3 km step size, where the negative value indicates a measurement pointing below the horizon. Additionally, a 35th spectrum with 150 km tangent height was obtained. For the sake of clarity only selected subsets of the 34 spectra are plotted in the figures.

The left columns show the raw signals recorded by the instrument. Four processing steps are applied to the counts recorded by SCIAMACHY’s electronics:

Fig. 3. Limb spectra recorded in channels 4 (top), 5 (middle), and 6 (bottom). Like Fig. 2, except for 22 km reference tangent height in channel 6 and logarithmic scaling in all plots. Tangent height set identical to the one of Fig. 2.
Division by the integration time of typically 0.375–1.5 s produces a “power-like” quantity (counts/s). The dark current is corrected for by subtraction of the “power-like” quantity at 150 km tangent height. The pixel number axis is substituted with a wavelength calibration obtained during the pre-flight characterization of SCIAMACHY. The calibration is stable on the sub-pixel scale. Unused and dead/bad pixels (≈9%) detected during the pre-flight characterization are omitted. The right columns show the spectra of normalized signals which are obtained from the raw signals by division with the raw signals for a reference tangent height. The latter is chosen to be 43 km for the channels 1–5 and 22 km for the channels 6–8. This choice is motivated by the requirement of a high signal to noise ratio in the reference. The normalized signals equal the analogously normalized radiances because of the linearity of the detector response.

3. Discussion

The raw signals, i.e., the left columns of Figs. 2–4, exhibit the atmospheric signature and additionally the Fraunhofer structure of the solar irradiance and instrument characteristics. The normalization removes the Fraunhofer structure and all multiplicative artifacts caused by the instrument. Thus the atmospheric features become clearly visible in the normalized radiances, i.e., the right columns of Figs. 2–4.

3.1. Fraunhofer lines

The raw signals exhibit the Fraunhofer lines of the extra-terrestrial irradiance. They originate from absorption in the solar atmosphere. Prominent examples are the absorption lines of Mg II (279.8 nm), Ca II (393.4 and 396.8 nm), H I β (486.1 nm), Na I (589.0 and 589.6 nm), and H I α (656.3 nm), cf. Zombeck (1990). Weak lines are abundant but more difficult to identify by eye, e.g., Fe/Ti (430.8 nm), H γ (434.0 nm), Mg (516.7, 517.3, 518.3 and 527.0 nm), Fe (516.9, 526.9 and 527.0 nm), and Ca (527.0 nm). (Moore, 2000).

3.2. Atmospheric signature

An exponential decrease of the normalized radiance with increasing tangent height can generally be observed in channels 2–6. The raw signals exhibit the decrease as
well. It is caused by the exponential decrease of the air density in the atmosphere since the air near the tangent point, the lowest point of the line of sight, generally scatters most of the observed radiation into the line of sight. In Fig. 4 (channels 7 and 8) the decrease is partially hidden by instrument noise.

The influence of the strong absorption in the stratospheric ozone layer is evident for wavelengths below about 340 nm. The differential structure of the Huggins bands is clearly visible in the normalized radiiances between 305 and 340 nm. Furthermore, the normalized radiances for tangent heights below about 46 km as well as their raw signals are all reduced to similar levels near 310 nm: due to the strong absorption the instrument can only see the atmosphere above the ozone layer no matter how low the tangent height is. Around 295 nm the radiance with about 46 km tangent height is actually the highest, as can be seen in the top right plot of Fig. 2. This so-called knee effect yields tangent height information in the spectra, (cf. Janz et al., 1996).

The ozone absorption structure of the Chappuis bands can clearly be seen in channel 3. The absorption near 575 nm is particularly strong for the two lowest bands can clearly be seen in channel 3. The absorption in this region.

Channel 4 features the oxygen A-, B-, and γ-bands near 760, 690, and 630 nm. Obviously, the strongest band (A-band) is dominated by emission for tangent heights above the middle stratosphere.

Water vapor absorption bands are evident in the spectra with tropospheric tangent heights near 725, 815, 900–980, 1110–1150, and 1350–1500 nm. The contrast between the very strong absorption for tropospheric tangent heights and virtually no absorption for all higher tangent heights highlights the extreme change of water vapor concentration across the tropopause.

The oxygen singlet delta band \( O_2 \Delta (0,0) \) near 1270 nm appears in absorption for tropospheric tangent heights and in emission for all stratospheric ones. Near 1590 nm the stratospheric spectra feature emission of the \( O_2 \Delta (0,0) \) band while the tropospheric spectra are dominated by carbon dioxide absorption signatures.

Methane absorption shapes the tropospheric spectra's structures in the 1620–1710 nm range.

A qualitative discussion of channels 7 and 8 is difficult as very many individual absorption lines are resolved and the relatively large noise in these channels requires statistical analysis. Nevertheless, the two carbon dioxide absorption bands of about 25 nm width around 1960 and 2010 nm are observed most obviously in channel 7. It is additionally influenced by water vapor and N\(_2\)O lines. Channel 8 features a mixture of methane, carbon monoxide, water vapor, and N\(_2\)O lines.

### 3.3. Instrumental features

The raw signals contain characteristic features of the instrument. The signals near the borders of channels 2–6 decrease since the instrument’s throughput is smaller in these regions than in the channels’ middle parts. The slight oscillation in the signals of channels 2 and 3 is caused by etalons which developed in the instrument.

The detector of channel 6 is made of two different types of InGaAs for radiation with wavelengths below and above 1590 nm. The material used for the longer wavelengths delivers noisier signals. A discontinuity is displayed where the detector material changes. Both effects have been anticipated.

The multiplicative instrument features can be eliminated by normalization. Other ones, e.g., due to polarization, have also been corrected for in ESA’s official data products, see http://envisat.esa.int/instruments/sciamachy/data-app/dataprod.html.

### 4. Conclusions

We have shown for the first time complete SCIAMACHY limb scattering spectra. Even though the spectra have not been processed and corrected for all known instrument effects, they display a richness of clear atmospheric features as well as solar irradiance structures. All the observed features agree nicely with the expectations, e.g., Kaiser and Burrows (2003, Fig. 2). Thus we conclude that SCIAMACHY is in very good shape and quantitative retrieval results of high quality can be expected from these limb measurements. First applications are presented by Eichmann et al. (2004) and von Savigny et al. (2004).

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### References


