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SCIAMACHY solar irradiance observation in the spectral range from 240 to 2380 nm

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Abstract

The SCanning Imaging Absorption Spectrometer for Atmospheric CHartographY (SCIAMACHY) is part of the payload of ESA's Environmental Satellite ENVISAT which was launched into a sun-synchronous polar orbit on 2002-03-01. It is the first spaceborne instrument covering a wavelength range from 240 to 2380 nm thus including ultraviolet, visible and near infrared spectral regions.

The main purpose of SCIAMACHY is to determine the amount and distribution of a large number of atmospheric trace constituents by measuring the radiance backscattered from the Earth. In addition, several solar observations are performed with daily or orbital frequency.

The presented results will cover the following topics: (a) comparison of the solar irradiance measured by SCIAMACHY with data from the instruments SOLSPEC/SOLSTICE/SUSIM and a solar spectrum derived by Kurucz; (b) comparison of the SCIAMACHY solar Mg II index with GOME and NOAA data; (c) correlation of the relative change of solar irradiance measured by SCIAMACHY with the sun spot index.

The mean solar irradiance for each of the 8 SCIAMACHY channels agrees with the Kurucz data within ±2–3%. The presented analysis proves that SCIAMACHY is a valuable tool to monitor solar irradiance variations.

Keywords: SCIAMACHY; Solar irradiance; Mg II index; Sun spot index

1. Introduction

ESA's new Earth observation satellite ENVISAT was launched successfully into a sun-synchronous polar orbit on 2002-03-01. Among nine other instruments, the passive remote sensing instrument SCIAMACHY (SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY) is part of the payload (Bovensmann et al., 1999, 2004). SCIAMACHY is an 8 channel spectrometer with 1024 spectral pixels per channel and the first spaceborne instrument covering a wavelength range from 240 to 2380 nm thus including ultraviolet, visible and near infrared spectral regions (see Table 1). Channels 1–6 (240–1750 nm) are contiguous, while channels 7 and 8 measure disjoint wavelength intervals around 2000 and 2300 nm.

The main purpose of SCIAMACHY is to determine the amount and distribution of a large number of atmospheric trace constituents by measuring the radiance backscattered from the Earth in limb and nadir geometry. In addition, several solar observations are performed with daily or even orbital (about 100 min) frequency using different combinations of mirrors and

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Table 1
Wavelength range, spectral resolution and detector material of the eight SCIAMACHY channels

Channel	Wavelength range in nm	Wavelength interval per pixel in nm	Spectral resolution (FWHM) in nm	Detector material
1	240(214)–314	0.12	0.24	Si
2	309–405	0.11	0.26	Si
3	394–620	0.24	0.44	Si
4	604–805	0.21	0.48	Si
5	785–1050	0.28	0.54	Si
6	1000–1750	0.78	1.48	InGaAs
7	1940–2040	0.11	0.22	InGaAs
8	2265–2380	0.12	0.26	InGaAs

diffusers to track the sun. These measurements offer the possibility to monitor solar variations on a dense time grid.

SCIAMACHY is a similar instrument like the European global ozone monitoring experiments GOME (launched 1995) and GOME2 (to be launched 2005). Together they provide a continuous record of solar and atmospheric observations that began in 1995 and will extend into the second decade of the 21st century.

2. Comparison of the solar irradiance measured by SCIAMACHY with SOLSPEC/SOLSTICE/SUSIM data and with a solar spectrum derived by Kurucz

First published SCIAMACHY solar irradiances (Bovensmann et al., 2002; Skupin et al., 2003) had radiometric offsets of about +10% (Fig. 1). Hence, the on-ground calibration was thoroughly revised and additional radiometric improvements from in-flight analyses were derived. As a result, an improved radiometric calibration of SCIAMACHY could be derived. It is still preliminary and not (yet) part of the operational SCIAMACHY data processing. The improvements include:

- adjustment of in-flight detector temperatures to on-ground calibration conditions;
- non-linearity correction for channels 6–8 (Kleipool, 2003);
- improved memory effect correction for channels 1–5 (Lichtenberg, 2003);
- corrected offset of pixel exposure time for channels 6–8 (Skupin et al., 2004);
- improved on-ground radiometric calibration (Skupin et al., 2004).

In addition, the radiometric calibration of the presented SCIAMACHY solar spectrum includes:

- subtraction of dark signal;
- a correction using measurements of the internal white light source (WLS), see below;
- spectral calibration derived in-flight using the internal spectral line source;
- Doppler shift correction (≈0.010 nm at 500 nm);
- subtraction of internal straylight;
- correction for sun–earth distance.

In contrast to the etalon correction defined for the SCIAMACHY operational processing (Slijkhuis, 2000), an alternative correction based on the ratio of dark signal corrected on-ground and in-flight WLS measurements is applied. The used in-flight WLS measurement has to be temporally close to the measurement that is to be calibrated. Besides etalon effects this method corrects for:

- on-ground to in-flight changes of radiometric sensitivity;
- change of radiometric sensitivity due to instrument degradation;
- throughput loss due to ice on detectors of channels 7 and 8[1].

Using WLS ratios for correction assumes a stable WLS performance which is not true for the lower UV part of the SCIAMACHY wavelength range. So instrumental and WLS degradation cannot be completely

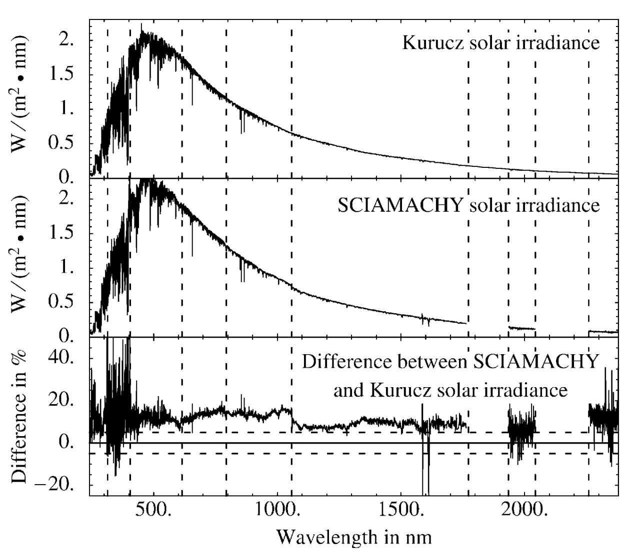

Fig. 1. Comparison of the solar irradiance measured by SCIAMACHY (without radiometric improvement, orbit: 2257, date: 2002-08-05) with a Kurucz spectrum showing an offset of about +10% (Skupin et al., 2003). SCIAMACHY channel boundaries are marked by vertical, the ±5% difference range by horizontal dashed lines.

[1] An ice layer buildup is observed on the detectors of channels 7 and 8 of SCIAMACHY causing an increasing throughput loss. The ice layer can be removed by decontaminating the instrument, but slowly regrows until the next decontamination (Noël et al., 2004).

separated in the UV. This leads to a possible broadband error of a few percent in channel 1.

The SCIAMACHY solar irradiance is validated with data from SOLSPEC (Thuillier et al., 2003), SOLSTICE (Rottman and Woods, 1994), SUSIM (Floyd et al., 2003) and with a solar spectrum derived by Kurucz (Kurucz, 1995). The Kurucz spectrum is based on the file `newkur.dat` taken from the atmospheric modeling program MODTRAN 3.7. To take care of the different spectral resolutions of the instruments, high resolution data are adapted to the lower resolution of the data it is compared with. i.e. the Kurucz spectrum (spectral resolution 0.005–0.57 nm in the SCIAMACHY wavelength range) is convoluted with the SCIAMACHY slit function (as given in the SCIAMACHY keydata derived from on-ground calibration measurements) to match the SCIAMACHY spectral resolution. The SCIAMACHY solar irradiance is binned to match the spectral resolution of the SOLSPEC spectrometer (spectral resolution 0.07–1.1 nm) and of the UARS instruments SOLSTICE and SUSIM. For the latter ones, data are available for wavelengths up to 420 nm with a spectral resolution of 1 nm. Due to this low spectral resolution, the UV Fraunhofer structures are smoothed out and a generally better agreement in the UV is achieved as with higher resolution data from SOLSPEC and Kurucz where, e.g., even small errors of the spectral calibration can lead to relatively large differences in irradiance.

Comparisons of the solar irradiance spectra from SCIAMACHY, SOLSPEC, SOLSTICE, SUSIM, and Kurucz are given in Figs. 2 and 3. The presented differences are calculated by ($\text{irradiance}_{\text{SCIAMACHY}}/\text{irradiance}_{\text{other data}}$)−1. Statistical results for each SCIAMACHY channel are given in Table 2. For the complete SCIAMACHY wavelength range from 240 to 2380 nm, the difference of the mean irradiance per channel to all other data sources is below ±5%. The comparison with Kurucz data results in deviations even below ±2–3% and thus matches the design goal of SCIAMACHY.

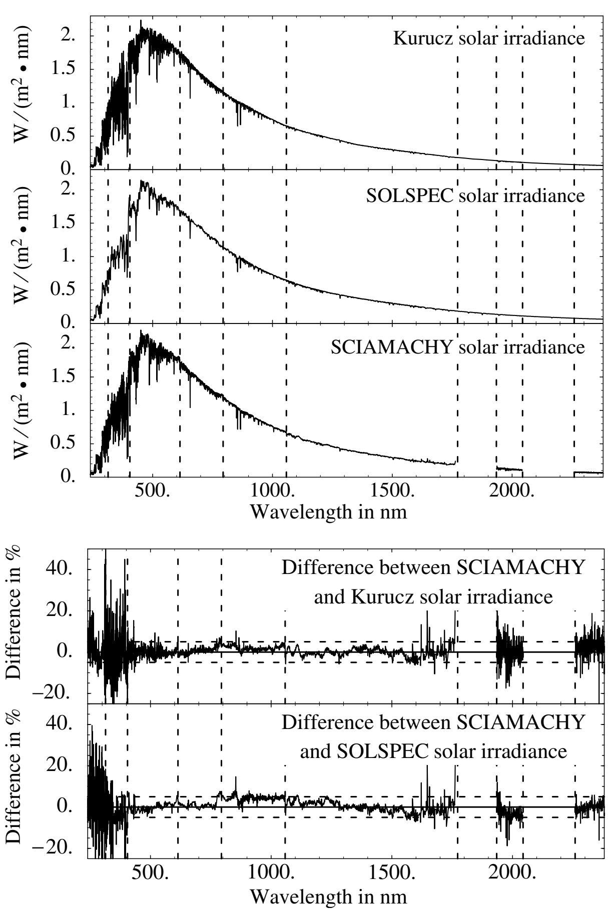

Fig. 2. Comparison of the radiometrically improved solar irradiance measured by SCIAMACHY (orbit: 10529, date: 2004-03-05) with Kurucz and SOLSPEC spectra. Upper: Irradiances. Lower: Differences in %. SCIAMACHY channel boundaries are marked by vertical, the ±5% difference range by horizontal dashed lines.

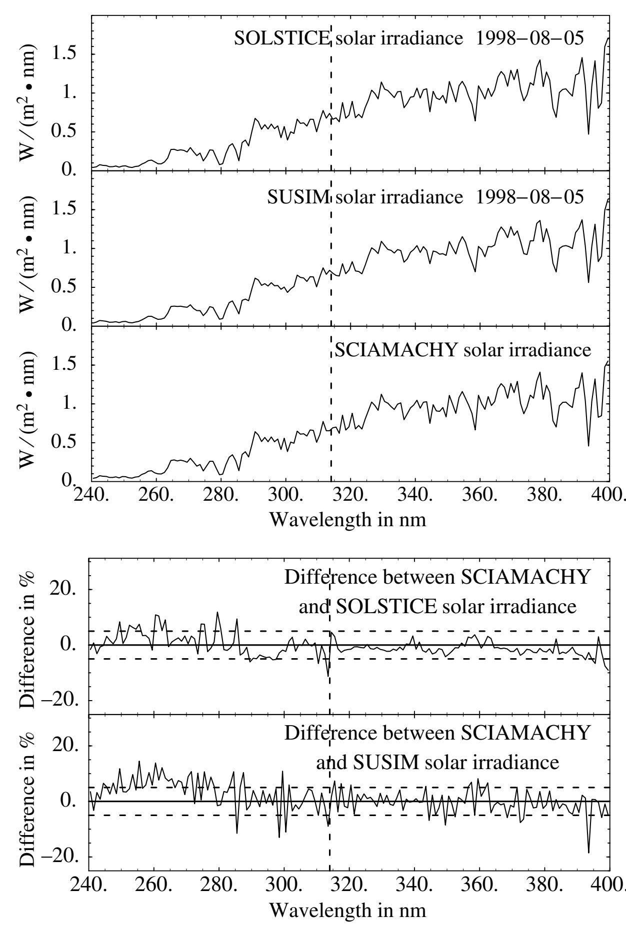

Fig. 3. Comparison of the radiometrically improved solar irradiance measured by SCIAMACHY (orbit: 10529, date: 2004-03-05) with the UARS instruments SOLSTICE and SUSIM. Upper: Irradiances. Lower: Differences in %. SCIAMACHY channel boundaries are marked by vertical, the ±5% difference range by horizontal dashed lines.

Table 2
Statistical results for the comparison between SCIAMACHY and other data

Channels							
1	2	3	4	5	6	7	8
Mean difference and standard deviation in % between SCIAMACHY without radiometric improvement and Kurucz solar spectra							
+11.52	+13.98	+11.36	+13.32	+13.85	+8.56	+6. 16	+12.02
±6.90	±11.41	±2.96	±1.89	±1.45	±2.98	±3.37	±3.99
Mean difference and standard deviation in % between SCIAMACHY with radiometric improvement and Kurucz solar spectra							
+0.62	−1.16	−0.18	+0.82	+1.96	−0.04	−0.27	+2.87
±6.43	±9.76	±2.53	±1.64	±1.22	±2.83	±4.21	±3.34
Mean difference and standard deviation in % between SCIAMACHY with radiometric improvement and SOLSPEC solar spectra							
+4.20	−2.73	+0.00	+1.25	+4.28	+0.11	−3.27	+0.02
±13.45	±9.20	±2.05	±1.88	±1.18	±2.85	±3.28	±2.50
Mean difference and standard deviation in % between SCIAMACHY with radiometric improvement and SOLSTICE solar spectra							
+0.80	−1.42	–	–	–	–	–	–
±4.55	±2.32	–	–	–	–	–	–
Mean difference and standard deviation in % between SCIAMACHY with radiometric improvement and SUSIM solar spectra							
+3.49	−0.42	–	–	–	–	–	–
±5.70	±4.10	–	–	–	–	–	–

The mean difference per channel and the standard deviation (with ± prefix) are given.

In Fig. 3, a positive offset at the lower end of channel 1 compared to the UARS instruments SOLSTICE and SUSIM is visible. In Table 2, the comparison with SOLSPEC gives a positive offset for channel 1 also. Besides the fact that there is a disagreement between the chosen validation sources of almost 4%, on the SCIAMACHY side this offset may be caused by the weak signal-to-noise ratio of the instrument calibration measurements or by the degradation of the internal white light source used for calibration. This is still under investigation.

The near infrared spectrum above 1586 nm (correlating with a change of the detector material in channel 6 at this wavelength) shows some noise. This may be caused by the unexpected feature that the performance of the SCIAMACHY IR detector pixels varies with time and has to be monitored regularly. This is not yet implemented and still under investigation (Kleipool, 2004). Offsets of around −3% in channel 7 when compared with SOLSPEC and +3% in channel 8 when compared with Kurucz data may result from a residual influence of the ice layer on these detectors which could not be completely eliminated by the used correction.

3. Comparison of the SCIAMACHY solar Mg II index with GOME and NOAA/SBUV2 instruments

Proxy solar activity indicators can be given by the core-to-wing ratio of selected Fraunhofer lines like the Magnesium II (Mg II) doublet at 279.9 nm. It has been shown that this Mg II index provides a good measure of the solar UV variability and can be used as a reliable proxy to model extreme UV variability during the solar cycle (DeToma et al., 1997; Floyd et al., 1998, 2003; Viereck et al., 2001; Weber et al., 1998). The major modulation of the Mg II index contains a periodicity of about 27–28 days (corresponding to the mean solar rotation period) and eleven years (associated with the change of solar activity due to the 22-year magnetic cycle of the sun).

The SCIAMACHY Mg II index starts in August 2002 and has been calculated until end of March 2004. Since GOME suffers from severe instrument and platform degradation, reliable GOME Mg II index data are only available until June 2003. In Fig. 4, the SCIAMACHY Mg II index time series is compared with GOME (Weber, 1999, 2004) and NOAA/SBUV2 (Puga and Viereck, 2004; Viereck and Puga, 1999) data. The differences between the indices are calculated by (Mg II index$_{\mathrm{SCIAMACHY}}$/Mg II index$_{\mathrm{other\ instrument}}$)−1, where the GOME and NOAA Mg II index time series are interpolated to the times of the SCIAMACHY measurements. The absolute values of the Mg II index depend on the instrumental slit width (spectral resolution) and the exact definition of the core-to-wing ratio and have to be linearly scaled to match each other.

The SCIAMACHY and GOME Mg II indices agree to within about 0.5%, the SCIAMACHY and NOAA Mg II indices to within about 0.25%. The correlation coefficient of the SCIAMACHY Mg II index with GOME as well as with NOAA data is 0.995, indicating excellent agreement in both cases. Pronounced deviations visible in the difference plots (e.g., in December 2002/January 2003, August 2003, and December 2003/January 2004) are correlated with thermal instabilities of SCIAMACHY caused by decontaminations or shutdowns. The 27–28 day periodicity as well as the declining phase of solar cycle 23 is clearly visible in all plots.

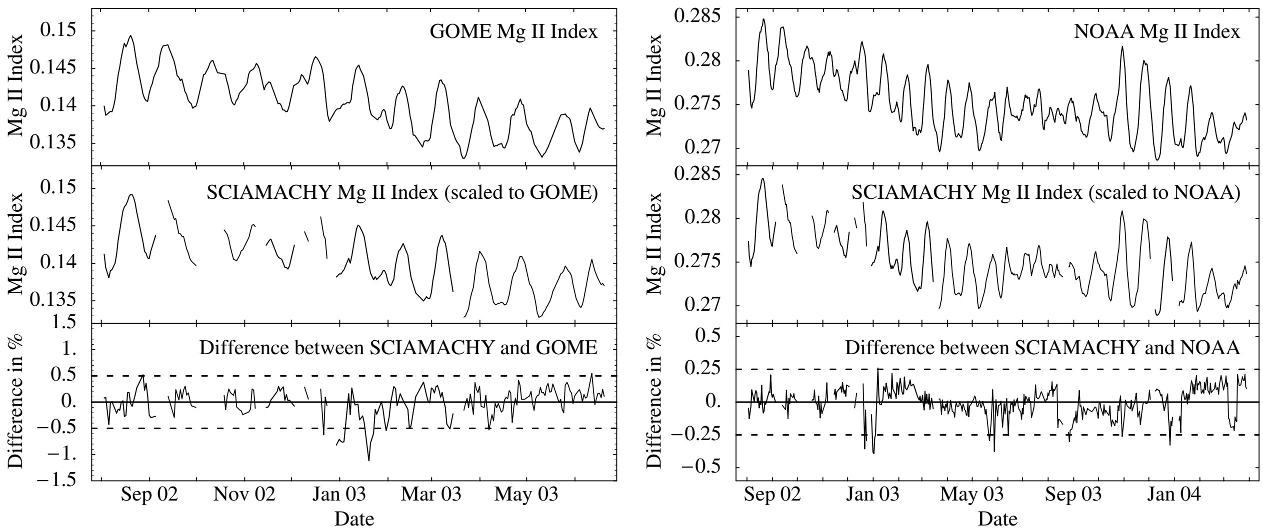

Fig. 4. Comparison of the SCIAMACHY Mg II index with GOME and NOAA/SBUV2 data.

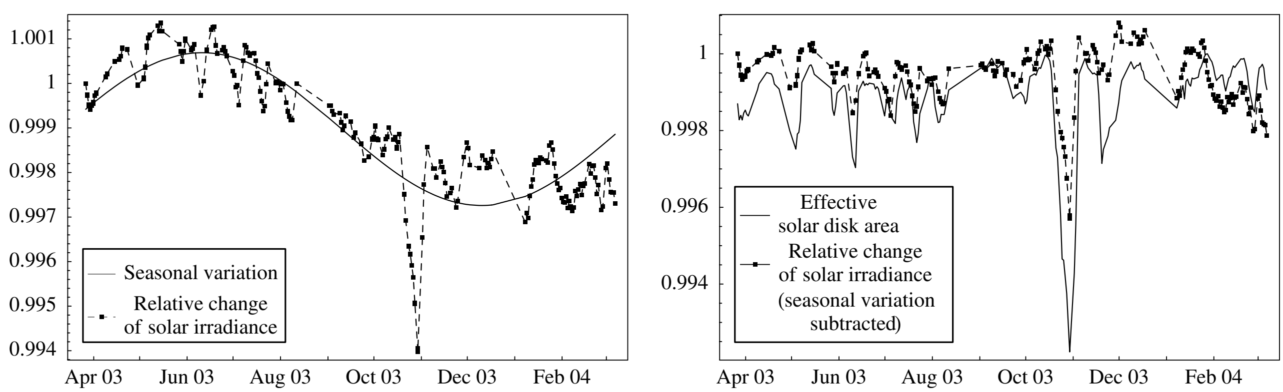

Fig. 5. Left: Correction of the relative change of solar irradiance measured by SCIAMACHY for seasonal variation. Right: Comparison of the effective solar disk area with the relative change of solar irradiance measured by SCIAMACHY in the wavelength range of the solar irradiance maximum around 500 nm (SCIAMACHY channel 3).

The presented SCIAMACHY timeseries includes only one kind of diffuser measurement performed daily. There are gaps in the available data caused by incomplete data distribution and instrument decontaminations/calibrations. For future analyses, it is planned to include all available solar measurements to close these gaps.

4. Correlation of the relative change of solar irradiance measured by SCIAMACHY with the sun spot area

In the visible wavelength range, sun spots lead to a reduction of the effective solar disk area given by 1–Greenwich Sun Spot Area (GSA, 2004). To compare with SCIAMACHY the effective solar disk area timeseries is interpolated to the times of the SCIAMACHY measurements. For the relative change of the solar irradiance the wavelength range around the solar irradiance maximum (≈500 nm, SCIAMACHY channel 3) is used.

A weak seasonal variation of the relative change of solar irradiance measured by SCIAMACHY (see left part of Fig. 5) was fitted and subtracted from the data. The comparison of the remaining relative change of solar irradiance measured by SCIAMACHY and the effective solar disk area is shown in the right part of Fig. 5. After the subtraction of the seasonal variation, the correlation coefficient between the SCIAMACHY timeseries and the effective solar disk area is with 0.798 very good.

5. Conclusion

The SCIAMACHY solar irradiance was validated with a Kurucz spectrum and with SOLSPEC/SOLSTICE/SUSIM data. In comparison with the Kurucz spectrum, the mean absolute radiometric accuracy per channel is better than 2–3% for the complete SCIAMACHY wavelength range from 240 to 2380 nm.

It was demonstrated that SCIAMACHY solar observations can be utilized to derive a time series of a proxy solar activity indicator, the so called Mg II index. An excellent correlation of 0.995 with Mg II indices from GOME and NOAA has been achieved. This shows that spectral structures in solar irradiance like the Mg II doublet lines are measured by SCIAMACHY accurately and with long term stability.

The good correlation of 0.798 between the relative change of solar irradiance measured by SCIAMACHY and the effective solar disk area demonstrates that in the visible wavelength range SCIAMACHY is capable to measure relative changes of the solar irradiance in the order of 10^{-3}.

Although SCIAMACHY was primarily designed for atmospheric remote sensing it could be shown that it is also a valuable tool for monitoring solar irradiance variations. It offers the unique opportunity to observe the sun every 100 min in the wavelength range from 240 to 2380 nm.

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