SCIAMACHY REFLECTANCE AND SOLAR IRRADIANCE VALIDATION

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ABSTRACT

The top-of-atmosphere spectral reflectance measured by SCIAMACHY has been validated by comparisons between calibrated SCIAMACHY V6 Level 1 data and corresponding reflectances from AATSR and MERIS. The AATSR analysis is currently restricted to part of one specifically processed orbit containing a scene over a hurricane with high and homogeneous clouds for which results for V5 data are already available. The MERIS intercomparison is based on one individual state over Europe. These first comparisons between AATSR/MERIS and SCIAMACHY reflectances show a substantial improvement of the radiometric calibration of SCIAMACHY, although discrepancies still remain, especially at the wavelength 1600 nm.

Furthermore, SCIAMACHY solar irradiances from the V6 Level 1 product have been compared with calibrated solar measurements by the LPMA/DOAS spectrometer which has been flown during various balloon campaigns (Kiruna 2003, Aire Sur l'Adour 2003, Kiruna 2004, Teresina 2004, 2005), SIM (Spectral Irradiance Monitor) UV/Vis/NIR spectra, the Atlas-3 shuttle composite spectrum, and the Kurucz solar reference spectrum. From these comparisons we conclude that an overall substantial improvement of SCIAMACHY V6 irradiances has been achieved, in particular with respect to the known irradiance offset (10-20%) in V5. The data in the overlap regions between channels have also improved but results are still not satisfactory there.

1. INTRODUCTION

As it has been derived by various intercomparisons, SCIAMACHY [1] operational irradiance and radiance data products before version 6 showed significant deviations compared to correlative measured or modelled data (see e.g. [2]–[8]). Whereas SCIAMACHY irradiances were typically too high by about 10%, reflectances turned out to be about 10–25% too low. These deviations could be tracked down to inappropriate radiometric key data.

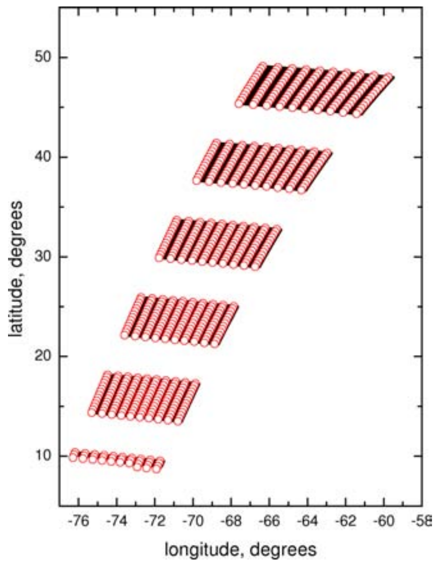


Figure 1. Location of SCIAMACHY pixels analysed in the AATSR comparison.

Based on a re-analysis of on-ground calibration data a new set of radiometric key data has been derived (see [9, 10] for details) which became active in Version 6 of the SCIAMACHY Level 1 products.

In this paper we compare the V6 SCIAMACHY reflectances and irradiances with various independent data sources to assess the quality of the new Level 1 data product.

2. REFLECTANCE VALIDATION

2.1. Comparison with AATSR

This section is aimed at the exploration of AATSR-SCIAMACHY top-of-atmosphere spectral reflectance differences for the case of data from three SCIAMACHY states shown in Fig. 1. The states belong to orbit 08095

Proceedings of the Third Workshop on the Atmospheric Chemistry Validation of Envisat (ACVE-3)
4-7 December 2006, ESRIN, Frascati, Italy (ESA SP-642,February 2007)

wavelength, nm	A	B	C
550	1.063	0.002	0.993
670	1.027	0.003	0.997
870	1.060	0.006	0.997
1600	0.792	0.013	0.994

Table 1. Coefficients A and B from Eq. 2 and corresponding correlation coefficient C. SCIAMACHY reflectances were averaged in the spectral ranges 545–565, 660–680, 860–886, and 1549–1570 nm to match the spectral widths of AATSR channels. AATSR reflectances were averaged to match the spatial resolution of SCIAMACHY.

of ENVISAT (17.09.2003, around 14:50 UTC), for which V6 Level 1b data have been provided by DLR. The scene is as in [8] and covers a large range of reflectances. The middle state contains a hurricane (Isabel) with a very high reflectivity, but there are also cloud-free pixels over ocean where the reflectivity is low.

The results are shown in Fig. 2 for four channels of AATSR. AATSR data were averaged with respect to the large SCIAMACHY ground scene. SCIAMACHY data were averaged with respect to the broader spectral channels of AATSR centred around 550, 670, 870, and 1600 nm. It was found that reflectances measured by the two independent instruments highly correlate.

The reflectance R is defined as

$$R = \frac{\pi I}{E_0 \cos\theta_0} \tag{1}$$

Here I is the top-of-atmosphere reflected light intensity, θ_0 is the solar zenith angle, E_0 is the solar top-of-atmosphere irradiance on the area perpendicular to the solar beam. The value of R depends on the wavelength and it is larger than approximately 0.2 for cloudy pixels in the visible.

The coefficient of correlation is in all cases larger than 0.99. The AATSR reflectances are somewhat larger than the SCIAMACHY reflectances (except at 1600nm). However, the coefficient A (see Tab. 1) in the equation

$$R_{\text{aatsr}} = A R_{\text{scia}} + B \tag{2}$$

(where R_{aatsr} and R_{scia} are the AATSR and SCIAMACHY reflectance, respectively) is closer to 1.0 as compared to the same case studied using processor 5 data (see, e.g., [8]). In particular, the coefficient A was reduced from 1.21 to 1.063 (550 nm), 1.19 to 1.027 (670 nm), 1.23 to 1.06 (870 nm) for processor 6 as compared to processor 5. The differences increased at 1600 nm (1.1 for processor 5 as compared to 0.792 for processor 6, see Tab. 1). The bias B is negligibly small for all wavelengths.

Taking into account that AATSR has slightly larger reflectances at 550 nm as compared to MERIS, we can conclude that SCIAMACHY re-calibrated data are very much improved in the region 550–870 nm. There is

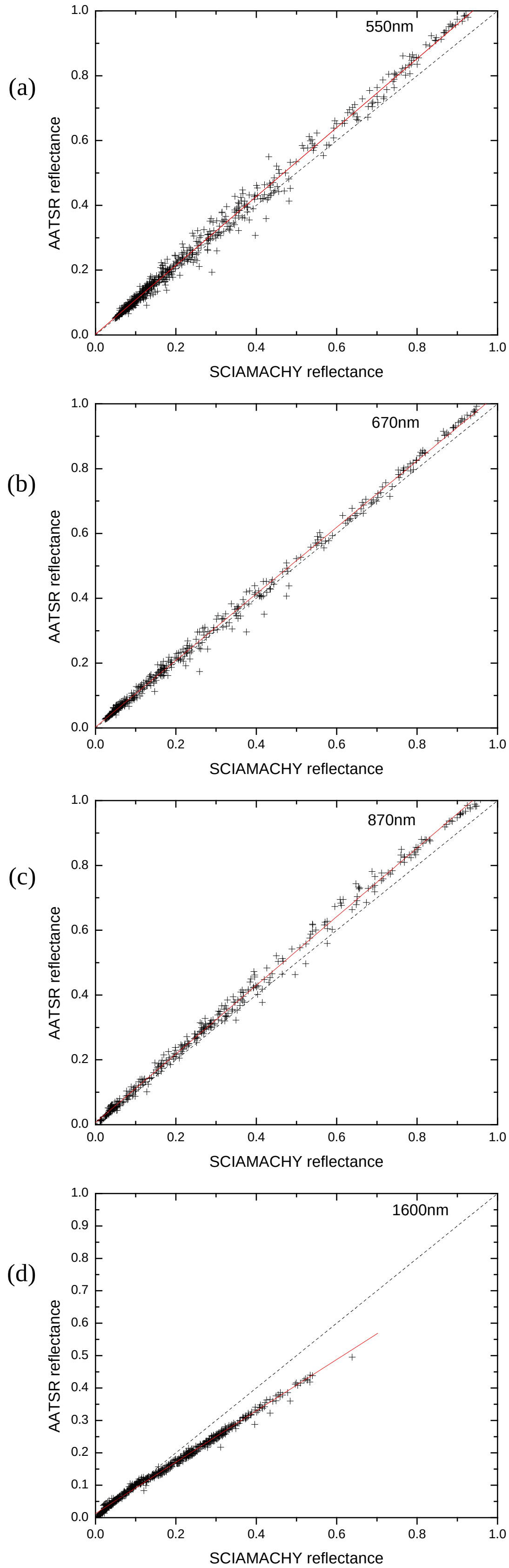


Figure 2. Correlation between SCIAMACHY and AATSR reflectances at (a) 550 nm, (b) 670 nm, (c) 870 nm and (d) 1600 nm

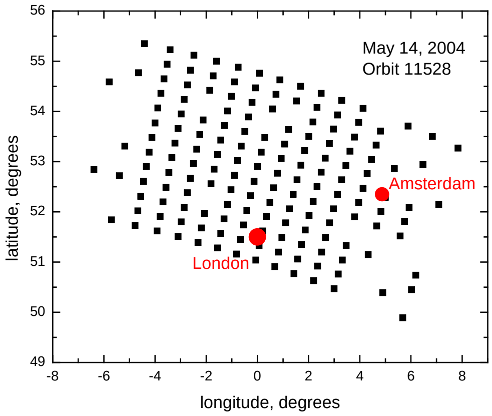


Figure 3. Location of SCIAMACHY 30 $\times$ 60 km^2 pixels (black squares). One SCIAMACHY state for ENVISAT orbit 11528 (May 14, 2004) is shown.

still disagreement at 1600 nm, where SCIAMACHY reflectances are too large as compared to AATSR.

The results are preliminary and must be confirmed using larger datasets of AATSR and MERIS measurements.

2.2. Comparison with MERIS

MERIS provides the spectral top-of-atmosphere reflectance at 15 channels in the wavelength range λ = 412–900 nm with widths depending on the channels but not larger than 10 nm for most of channels. The spatial resolution of MERIS is 1.2 $\times$ 1.2 km^2 (in reduced resolution mode) as compared to 30 $\times$ 60 km^2 (or even larger pixel sizes depending on spectral channels) for SCIAMACHY. Therefore, a single SCIAMACHY pixel contains about 1200 measurements of MERIS. This can be used, e.g., for the improvement of SCIAMACHY cloud screening algorithms because measurements by both instruments are performed at the same time and space. For this and also for other applications it is of importance to understand if MERIS and SCIAMACHY reflectances for the same area coincide. This can be done by spatially averaging MERIS reflectances to match the larger SCIAMACHY ground scenes and spectrally averaging SCIAMACHY reflectances taking into account the MERIS spectral response functions for each channel. Such a work has been performed for SCIAMACHY V5 Level 1b data by [5, 7, 11]. It was demonstrated that differences can reach 20% depending on the channels. Here we compare reflectances as measured by MERIS and SCIAMACHY taking into account the new SCIAMACHY calibration of the Level 1b products V6.

MERIS and SCIAMACHY reflectances were intercompared for the SCIAMACHY state shown in Fig. 3. A MERIS browse image of the orbit studied is shown in Fig. 4. One can see that a broken cloud field existed over the UK and parts of Western Europe during the measurements. Both clear and cloudy pixels over land and ocean

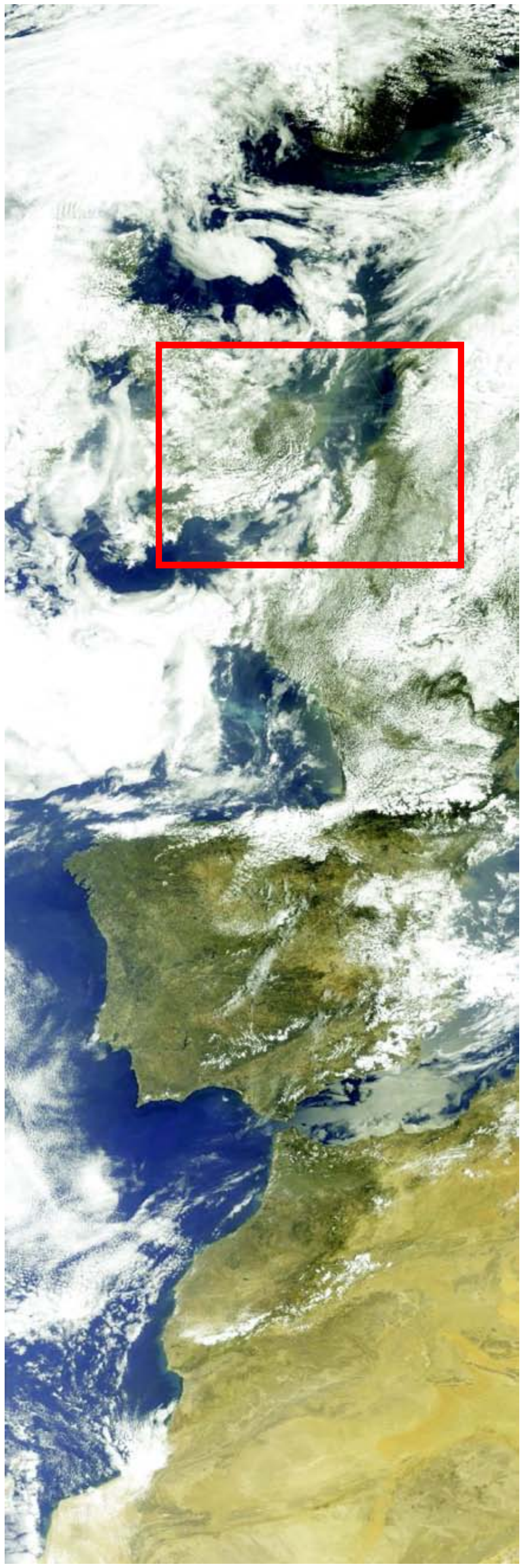


Figure 4. MERIS browse image of (part of) orbit 11528. The approximate location of measurements is shown by a box.

wavelength, nm	A	B	C
443	1.0017	0.0010	0.9975
560	1.0135	-0.0016	0.9890
665	1.0106	0.0008	0.9966
754	1.0099	0.0002	0.9899
865	1.0375	-0.0007	0.9978

Table 2. Parameters of Eq. 3 found using data shown in Fig. 5. Also the correlation coefficient C is given.

were used in the intercomparison study. This enables to cover almost the entire range of the reflectance variability.

The results of the intercomparison study are reported in Fig. 5 and also in Tab. 2, where the coefficients A and B of the statistical relationship

$$R_{\mathrm{meris}} = AR_{\mathrm{scia}} + B \tag{3}$$

are given.

The analysis of data leads to the conclusion that current SCIAMACHY reflectance measurements are highly accurate (at least in the spectral range covered by MERIS, 400–900 nm). The calibration of SCIAMACHY was improved considerably as compared to the SCIAMACHY Processor 5 version data. The difference Δ between MERIS and SCIAMACHY measurements of R is close to the MERIS calibration error [12]. Δ slightly increases with the wavelength (see Tab. 2). Taking into account that B is a small number we have: $R_{\mathrm{scia}} \simeq 0.99R_{\mathrm{meris}}$ in the visible. This is an excellent result, which will enable accurate retrievals of atmospheric parameters like cloud and aerosol optical thicknesses as soon as all SCIAMACHY data are reprocessed using Processor 6. The difference of MERIS and SCIAMACHY at 865 nm is around 4% with the underestimation of R by SCIAMACHY. If this is due to MERIS or SCIAMACHY (or both) remaining calibration errors is not clear at this moment. The comparison with AATSR showed that results for the constant A are similar to those of MERIS at 670 and 870 nm. However, there is a difference in the constant A around 550 nm between MERIS and AATSR, which can be related to the AATSR calibration error at this channel.

3. IRRADIANCE VALIDATION

3.1. LPMA-DOAS Comparisons

The LPMA/DOAS payload has been flown during various balloon campaigns (Kiruna 2003, Aire Sur l'Adour 2003, Kiruna 2004, Teresina 2004, 2005). The DOAS spectrometer was calibrated on site (see [3]), such that absolutely calibrated irradiance spectra in the UV-VIS spectral region could be derived. These irradiance spectra have been compared to SCIAMACHY data (V5 and V6) and the Kurucz reference spectrum [13, 14]. All data have been scaled to 1 AU. Note that the SCIAMACHY

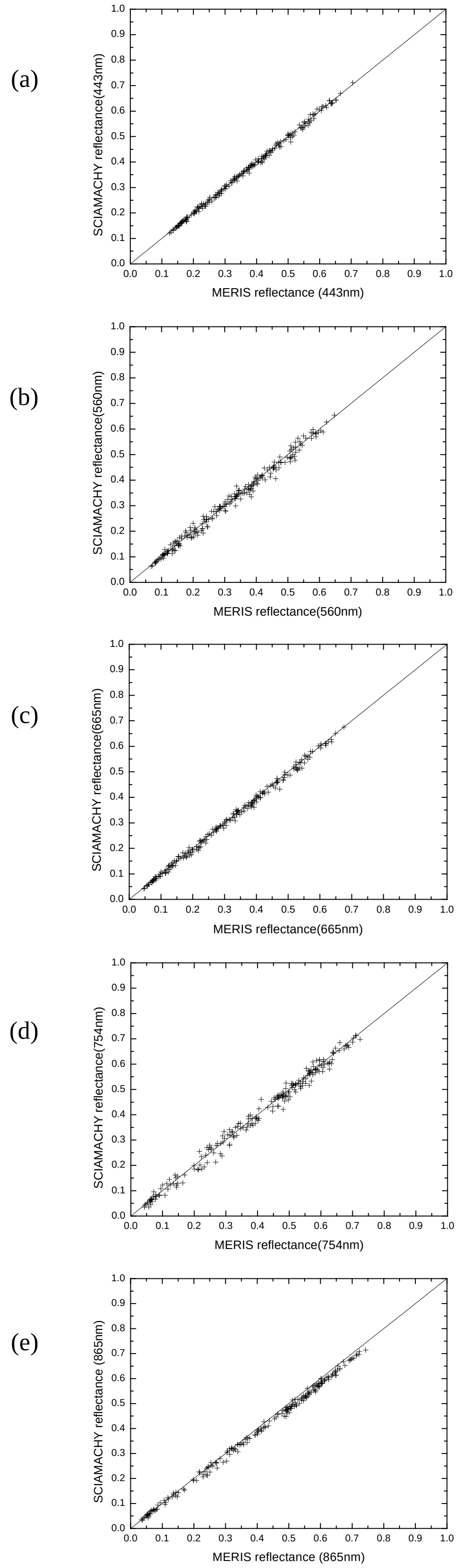
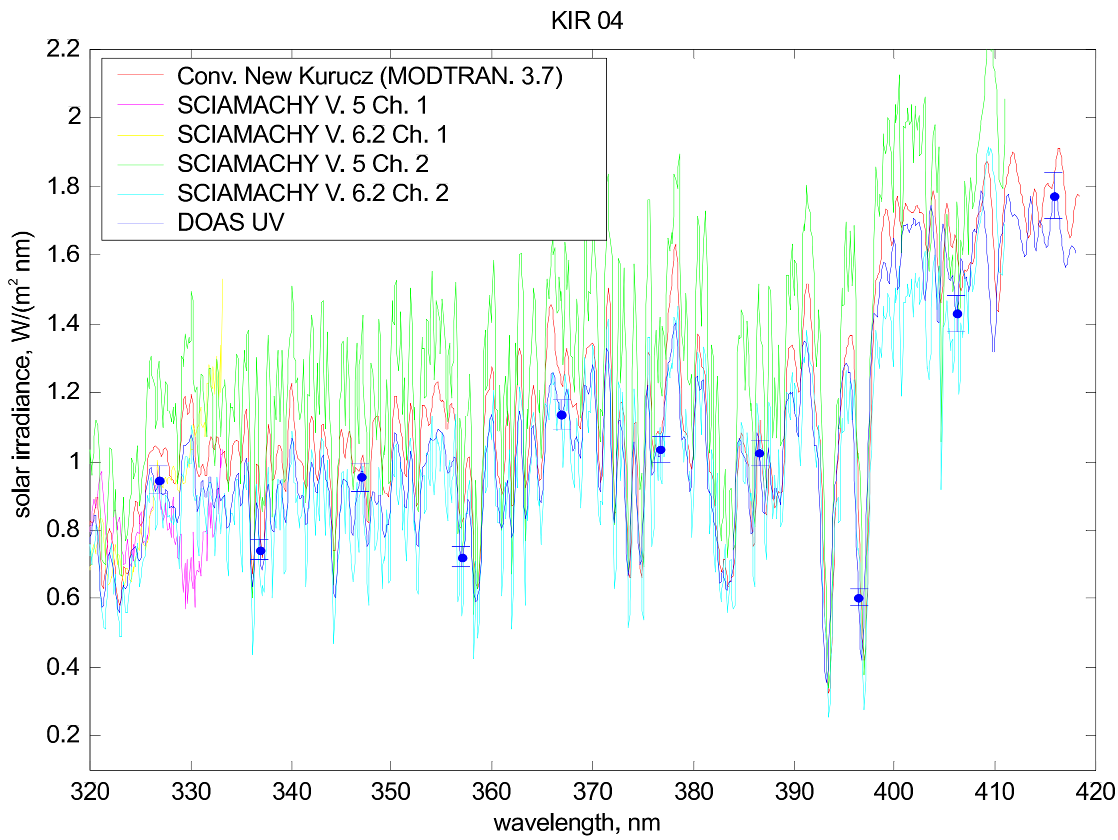


Figure 5. Correlation between MERIS and SCIAMACHY reflectances for wavelengths (a) 443 nm, (b) 560 nm, (c) 665 nm, (d) 754 nm, (e) 865 nm.

(a)



(b)

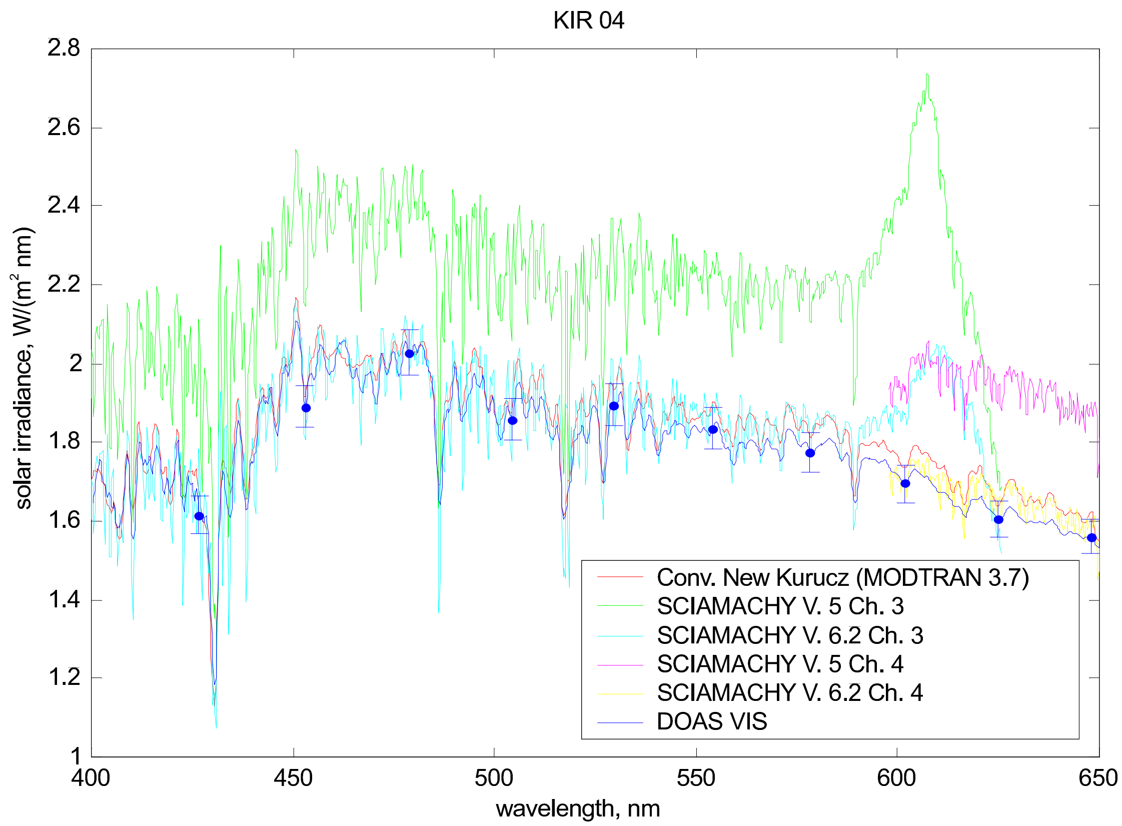


Figure 6. Comparison of solar irradiances derived during the Kiruna 2004 campaign with SCIAMACHY data and the Kurucz reference. a) Results for the DOAS-UV spectrometer. b) Results for the DOAS-VIS spectrometer.

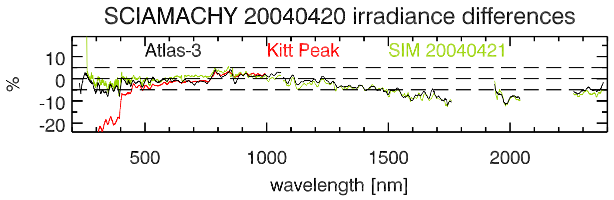


Figure 7. Comparison of SCIAMACHY irradiance from April 20, 2004, with Atlas-3 composite, Kitt Peak, and SIM. Shown are (SCIA-reference)/reference in %.

V6 data have been taken from the NRT distribution, not the validation master set. As an example, results of the comparison for the Kiruna 2004 campaign are shown in Fig. 6.

It can be concluded that SCIAMACHY V6 irradiances compare well with independent balloon data and the Kurucz reference spectrum.

There is an overall substantial improvement compared to version 5, especially the irradiance offset (10-20% for V5 data) is removed. Also the data in the overlap regions are improved but the situation is still not satisfactory there. Especially at the end of channel 2 and 3 discrepancies are found.

Note that deviations in the UV may be partly explained by a (currently uncorrected) degradation of SCIAMACHY (see e.g. [15, 16]) and the larger error of the DOAS calibration due to the weak UV output of the NIST FEL lamp.

3.2. Comparison with SIM, Atlas-3 and Kurucz reference spectra

In Fig. 7 the SCIAMACHY solar irradiance from April 20, 2004 has been compared with the SIM (Spectral Irradiance Monitor) [17], the so-called Atlas-3/Eureka composite recorded from a Shuttle experiment [18], and the FTS spectrum from the Kitt Peak Solar Observatory [13]. The SCIAMACHY solar irradiance data are from V5, where in addition the suggested radiometric corrections, now implemented in V6, and a internal white light source (WLS) lamp ratio correction (in-flight just after launch ratioed to preflight) has been applied. The WLS correction scheme has been modified from the one described in [19].

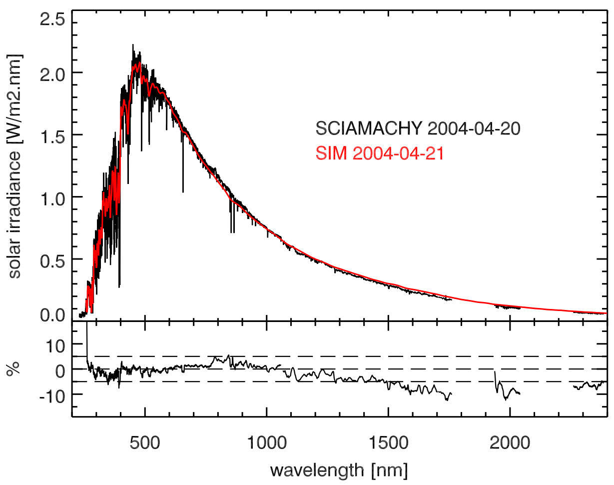


Figure 8. Top: SCIAMACHY and SIM irradiance in April 2004. Bottom panel shows the difference to SIM in %.

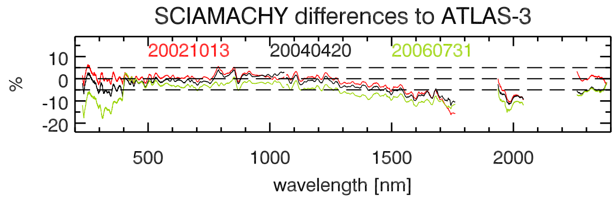


Figure 9. Difference of SCIAMACHY irradiances from 2002, 2004, and 2006 to Atlas-3 composite in %.

In general the agreement is very good up to 1000 nm. The Kitt Peak data apparently are higher than all other data below 400 nm. The differences between the SCIAMACHY solar irradiances and the other reference data is to within the uncertainties of the calibration standards. This is consistent with the MERIS and AATSR intercomparison results for this wavelengtn range presented above. In the long-wave region (beyond 1000 nm) the SCIAMACHY solar irradiance tends to be lower than the SIM data and the Atlas-3/EUREKA composite by about 5-10%. A too small solar irradiance in the near IR leads to the overestimation of R at is follows from Eq. 1. Such an overestimation of SCIAMACHY IR reflectances is therefore consistent with the AATSR intercomparison results presented in Fig. 2d.

The two solar irradiance spectra from SCIAMACHY and SIM are shown in Fig. 8. SIM and SCIAMACHY are the first instruments providing daily irradiance data covering the entire optical range, however, SCIAMACHY has a higher spectral resolution, particularly in the long-wave part of the spectrum.

A comparison of SCIAMACHY for three different dates in 2002, 2004, and 2006 with the Atlas-3 composite is shown in Fig. 9. The spectrum from 2006 is from the NRT data set in data version 6, while the other SCIAMACHY data are V5 with the radiometric and WLS corrections described above. In general there are only small changes with time, except for the UV spectral region which clearly shows the progression of the UV degradation.

All in all, the results shown in Figs. 7–9 are consistent one with another and also with the MERIS and AATSR intercomparison study reported above.

4. CONCLUSIONS

First comparisons with AATSR and MERIS data show that at least in the UV-visible spectral region the SCIAMACHY reflectances have largely improved with the new V6 Level 1 product. Up to about 870 nm the reflectances from MERIS and SCIAMACHY agree within a few percent, compared to deviations of up to more than 20% for previous SCIAMACHY product versions. The agreement of SCIAMACHY reflectances with MERIS data is in general better than with AATSR. Especially at 1600 nm SCIAMACHY reflectances are about 20% higher than corresponding AATSR measurements. However, these preliminary results need to be confirmed by further investigations. A general problem in this context is the lack of adequate correlative reflectance or radiance data in the IR region.

The SCIAMACHY V6 irradiance product (D0 spectrum) has largely improved. As expected from earlier verification results, the about 10% offset to reference data (like Kurucz and LPMA DOAS spectra) is now essentially gone. There is however still room for improvement, especially in the channel overlaps and with respect to the correction of throughput changes due to degradation (in the UV) or icing effects (in the SWIR). Especially, the solar irradiance is underestimated by SCIAMACHY in the near IR (see Figs. 7–9). This is consistent with the too large SCIAMACHY reflectances as shown in Fig. 2d at λ=1600 nm.

ACKNOWLEDGEMENTS

SCIAMACHY is a national contribution to the ESA ENVISAT project, funded by Germany, The Netherlands, and Belgium. SCIAMACHY, MERIS and AATSR data have been provided by ESA. We thank G. Lichtenberg (DLR) for the provision of Level 1b data V6 for orbit 08095. This work has been funded by the BMBF via GSF/PT–UKF, by DLR–Bonn, and by the University of Bremen.

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