SCIAMACHY REFLECTANCE AND POLARISATION VALIDATION: SCIAMACHY VERSUS POLDER

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ABSTRACT

We compare reflectance and polarisation as measured by the imager POLDER and the spectrometer SCIAMACHY. Both instruments measure the Earth reflectance and the linear polarisation of the incident radiation. Our goal is to validate SCIAMACHY using POLDER as a reference. A fruitful comparison is only possible if we restrict ourselves to suitable, collocated data having identical solar and viewing angles. For the reflectance, we find a disagreement between POLDER and SCIAMACHY of 10–20%. For the linear polarisation, there is also a significant disagreement. We attribute both results to the current calibration problems of SCIAMACHY.

1. INTRODUCTION

The reflectance measured by a satellite instrument is the basis for all geophysical products derived from it. The most important parameter determining the quality of the reflectance is the radiometric calibration of the satellite instrument. In the beginning of 2003, it was found that the reflectance of the SCIAMACHY instrument [1] was suffering from severe calibration problems. Additionally, the SCIAMACHY polarisation retrieval was not able to produce reliable polarisation data. In this paper, we intercompare the reflectance and linear polarisation of the imager POLDER with that of SCIAMACHY. This is possible, because the POLDER instrument is well-calibrated [2], and is able to mimic the SCIAMACHY viewing geometry in great detail.

The paper is set up as follows. In section 2 we introduce the satellite instruments SCIAMACHY and POLDER. Section 3 explains the approach that was followed to intercompare the reflectance and polarisation products of the two satellite instruments. Section 4 presents the results of the intercomparison, for the Earth reflectance and for its degree of polarisation. The results are discussed. The paper ends with a summary and conclusion.

2. SHORT DESCRIPTION OF SCIAMACHY AND POLDER

2.1 SCIAMACHY

SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric Chartography) [1] was launched on 1 March 2002, onboard the Envisat satellite, into a near-polar, Sun-synchronous orbit, with an orbital period of about 100 min. The local crossing time of the equator is 10:00 a.m. SCIAMACHY has the ability to perform not only nadir measurements, but also limb measurements. These two measurement modes are being alternated along the orbit. The resulting data are stored in blocks, called "states". A nadir state covers an area of 960×490 km^2 (across track $\times$ along track).

The wavelength region covered by SCIAMACHY is 240–2380 nm, with a spectral resolution of 0.2–1.5 nm (see Table 1). The scanning sequence is made up of a 4 s forward scan and a fast 1 s reverse scan. The swath is 960 km wide. The nadir spectrum is divided into 56 wavelength regions, called "clusters", that are all read out with their own integration time (IT). This allows a higher spatial resolution for the most important spectral regions, at the expense of

Table 1. Optical parameters of the eight high-resolution spectral channels of SCIAMACHY, and of the seven broadband Polarisation Measurement Devices (PMDs).

channel	spectral range (nm)	resolution (nm)	PMD	spectral range (nm)	sensitive to	remark
1	240−314	0.24	0	$<$300	Q,U	model value
2	309−405	0.26	1	310−377	Q	
3	394−620	0.44	2	450−525	Q	
4	604−805	0.48	3	617−705	Q	
5	785−1050	0.54	4	805−900	Q	overlap PMD 7
6	1000−1750	1.48	5	1508−1645	Q	
7	1940−2040	0.22	6	2265−2380	Q	not used
8	2265−2380	0.26	7	802−905	U	overlap PMD 4

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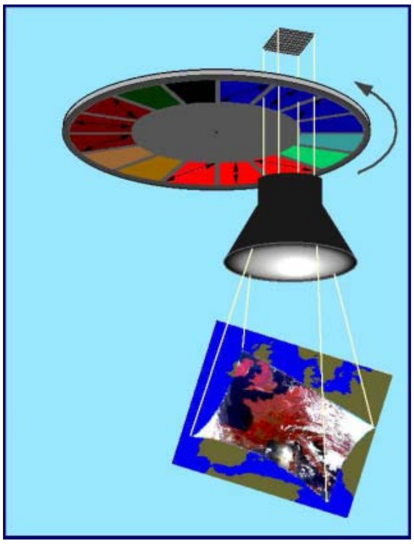

Fig. 1. The POLDER instrument is composed of a two-dimensional CCD detector array, wide field-of-view telecentric optics, and a rotating wheel carrying spectral and polarised filters. Picture taken from http://earth-sciences.cnes.fr/POLDER.

other wavelength regions where the spectrum is of less scientific interest, or would otherwise yield a weak signal. Typical ITs are 0.25 s (pixel size 60×30 km^2) and 1.0 s (pixel size 240×30 km^2). Global coverage is achieved in 6 days.

The polarisation of the detected radiation is measured at six independent wavelengths by so-called Polarisation Measurement Devices (PMDs). The optical parameters of these PMDs are given in Table 1. Here the specifications of the spectral channels are given as well. Note that below $\sim$300 nm, polarisation need not be measured, but may be calculated from single scattering equations. In Table 1, PMD '0' refers to this theoretical model value. More details about the SCIAMACHY instrument can be found in Bovensmann *et al.* [1].

2.2 POLDER

The first POLDER (Polarization and Directionality of the Earth's Reflectances) instrument [2] was launched in August 1996 onboard the Japanese ADEOS satellite. This satellite was put into a near-polar, Sun-synchronous orbit, with an orbital period of about 100 min. The main components of the imager are a bidimensional CCD detector, a wide field-of-view (FOV) focusing lens, and a rotating wheel which carries 15 optical filters and polarisers (see Fig. 1). As a result, POLDER is capable of measuring the Earth reflectance in nine spectral channel, located at eight different wavelengths (see Table 2). For three of these channels, polarisation is measured as well.

The second POLDER instrument, onboard ADEOS-2, measured the Earth's reflectance, and its polarisation, from December 2002 until the unfortunate loss of the ADEOS-2 satellite on 25 October 2003. An important and unique feature of the POLDER design is the fact that the measurements are repeated (every 19.6 s) in such a way that an image of an Earth scene overlaps largely with the previous image. As a result, a given point inside the POLDER swath may be observed by as much as 14 independent measurements, each having a different viewing geometry. The local crossing time of the equator is 10:30 a.m. for the descending node and the instrument's FOV is 2400 km with a resolution of 6×7 km^2 at exact nadir. Viewing angles up to 70° are reached. Global coverage of the Earth's surface is achieved virtually on a daily basis. More details can be found in Deschamps *et al.* [2].

Table 2. Overview of the POLDER spectral bands. The linear polarisation of the incident radiation is measured for three of the nine spectral bands.

POLDER band	**443**	**443P**	**490**	**565**	**670P**	**763**	**765**	**865P**	**910**
central wavelength (nm)	444.9	444.5	492.2	564.5	670.2	763.3	763.1	860.8	907.7
bandwidth (nm)	20	20	20	20	20	10	40	40	20
saturation level (norm. reflectance)	0.97	1.1	0.75	0.48	1.1	1.1	1.1	1.1	1.1
polarisation (Q, U)	–	Yes	–	–	Yes	–	–	Yes	–

3. INTERCOMPARISON

All the necessary steps are described below.

Collocation

Both satellites must follow the same orbit track for collocated data to be found. Because of the small difference in orbital period, such a situation only occurs once per $\sim$15 days. We selected a scene from SCIAMACHY orbit 7503 (software version 5.01) and POLDER-2 orbit 060/048 of 7 August 2003.

Scattering geometry

The scattering geometry is determined by the viewing geometry of the satellite instrument and the Sun. Because of the many viewing directions of POLDER, it is indeed possible to find, for every SCIAMACHY observation, a POLDER measurement that mimics the SCIAMACHY viewing geometry. Note that we neglect the effect of the (small) difference in solar geometry between POLDER and SCIAMACHY collocated data. The effects are very small. An estimation of the effect of the different solar geometries can be found in [6].

Spatial averaging

The pixel sizes of POLDER and SCIAMACHY are different (6×7 km^2 for POLDER versus 60×30 km^2 or 240×30 km^2 for SCIAMACHY). To solve this problem, we start with out with a SCIAMACHY pixels, and collect all suitable POLDER pixels that lie inside the SCIAMACHY pixel. The POLDER pixels are then averaged, i.e. we construct spatially averaged POLDER reflectance and polarisation data with the same footprint as the SCIAMACHY pixel.

Reflectance

In order to compare the SCIAMACHY reflectance with that of POLDER, we first have to convert the SCIAMACHY spectrum into nine broadband reflectances, which we can then compare with the POLDER spectral bands. This is done by integrating the SCIAMACHY reflectance spectrum, multiplied by the sensitivity functions of the POLDER spectral channels, over the wavelength spectrum. As the IT varies over the SCIAMACHY spectrum, sometimes the intercomparison could not be performed for the smallest IT of 0.25 s. Then an IT of 1.0 s was used.

Polarisation

From Tables 1 and 2 it can be found that we can compare polarisation data of SCIAMACHY PMDs 2, 3, and 4 with polarisation data of POLDER spectral bands 443P, 670P, and 865P. Note that there are small differences in the specifications of the sensitivity distributions. The effects were estimated to be small.

4. RESULTS

4.1 Reflectance

The result of the reflectance intercomparison is shown in Table 3. For each of the nine POLDER spectral bands we specify the central wavelength, the SCIAMACHY IT which was used for the intercomparison, and the fit results for the linear fit through the data of POLDER reflectance versus SCIAMACHY reflectance. Note that the slope is deviating from one significantly for all wavelengths λ_i, in this case pointing to an underestimation of the reflectance by SCIAMACHY. The fits were based on cloud-free data only. Analysis of the data showed that the intercomparison is better for cloud-free data. This is because cloudy pixels are more likely to change during the time interval between POLDER and SCIAMACHY's overpasses ($\sim$30 min). Also, by avoiding cloudy data we avoid saturation for POLDER channel 565 (cf. Table 2).

Table 3. Fit results of the reflectance intercomparison of this paper. The slope is the one of the reflectance ratio POLDER-SCIAMACHY. It deviates from one. The correlation is good, as can be concluded from the standard deviation.

associated POLDER band i	**443**	**443P**	**490**	**565**	**670P**	**763**	**765**	**865P**	**910**
central wavelength λ_i (nm)	444.9	444.5	492.2	564.5	670.2	763.3	763.1	860.8	907.7
associated SCIAMACHY IT (s)	0.25	0.25	0.25	1.0	0.25	0.25	1.0	0.25	0.25
slope s_i	1.119	1.121	1.125	1.136	1.141	1.186	1.162	1.199	1.207
standard deviation in slope σ_i	0.027	0.027	0.028	0.061	0.020	0.027	0.047	0.017	0.023

The deviation of the slope s_i from one is pointing to a significant radiometric calibration problem for SCIAMACHY. Note that it is already well-known that SCIAMACHY has calibration problems. See for instance [3, 4, 5, 6]. The deviations reported in these papers are in full agreement with the deviations we find. Therefore, we must conclude that SCIAMACHY has a serious calibration problem in the visible wavelength range 400–1000 nm.

4.2 Polarisation

In Fig. 2 we present the results of the polarisation intercomparison. On the vertical axis we present the degree of polarisation for POLDER spectral bands 443P, 670P, and 865P, respectively. On the horizontal axis is given the degree of polarisation measured by SCIAMACHY PMDs 2, 3, and 4. Cloudy pixels are indicated by blue crosses, cloud-free pixels are represented by green plusses. A linear fit through the data is given. Slope and accuracy (σ) are given as well. As can be seen, there is only a poor correlation. For PMD 2 there is not a very strict correlation, and the slope of the fit is 0.85 $\pm$ 0.15, significantly less than 1. For PMD 3 the correlation is better, but the slope of the linear fit is even lower, 0.76 $\pm$ 0.17, to be precise. PMD 4 shows a lot of serious errors, although part of the data do show a similar correlation as the other PMDs. For PMD 4, a linear fit is not presented. It is unclear what exactly causes the discrepancies.

Note that the existence of errors in the polarisation product has been known for quite some time now. In the past, errors in the polarisation product could be detected directly, by the existence of unphysical values in the polarisation product [7], or indirectly, by the existence of spectral polarisation features remaining in the reflectance after polarisation correction [8]. Another thing known for some time is the fact that the polarisation product is getting worse with increasing wavelength. This is something we also see in Fig. 2. In conclusion, we must conclude that the current SCIAMACHY polarisation product (software version 5.01) is seriously lacking quality for at least PMDs 2, 3, and 4.

5. SUMMARY & CONCLUSION

We presented new work on the validation of the radiometric calibration and polarisation detection of SCIAMACHY. The validation relied on a careful intercomparison of the SCIAMACHY reflectance and degree of polarisation with data of the imager POLDER. From the intercomparison it follows that SCIAMACHY systematically underestimates the Earth reflectance by as much as 10–20% in the wavelength range 400–1000 nm. This applies to software version 5.01. Note that this result is supported by other studies. From the intercomparison of the Earth polarisation we must conclude that PMDs 2, 3, and 4 are currently producing unreliable polarisation data. For PMD 4 the problems are the worst. At this point it is unclear where the errors and discrepancies come from.

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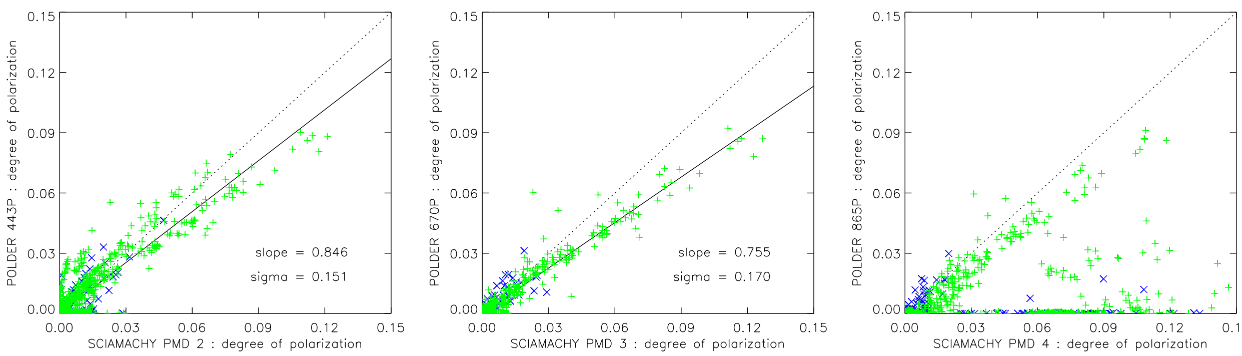

Fig. 2. Polarisation of POLDER versus that of SCIAMACHY, for the three mutual polarisation bands that can be intercompared (POLDER bands 443P, 670P, and 865P versus SCIAMACHY PMD 2, 3, and 4). Clearly, all three SCIAMACHY PMDs show errors. Blue crosses indicate cloudy pixels, green plusses are cloud-free pixels.

6. REFERENCES

1. Bovensmann H., Burrows J. P., Buchwitz M., Frerick J., Noël S., Rozanov V. V., Chance K. V. and Goede A. P. H., SCIAMACHY: Mission objectives and measurement modes, *J. Atmos. Sci.*, Vol. 56, 127 150, 1999.

2. Deschamps P.-Y., Bréon F.-M., Leroy M., Podaire A., Bricaud A., Buriez J.-C. and Sèze G., The POLDER mission: Instrument characteristics and scientific objectives, *IEEE Trans. Geosci. Remote Sens.*, Vol. 32, 598 615, doi:10.1109/36.297978, 1994.

3. Acarreta, J. R. and Stammes P., Calibration comparison between SCIAMACHY and MERIS onboard ENVISAT, *IEEE Geosci. Remote Sens. Lett.*, Vol. 2, 31 35, doi:10.1109/LGRS.2004.838348, 2005.

4. Tilstra L. G., van Soest G. and Stammes P., Method for in-flight satellite calibration in the ultraviolet using radiative transfer calculations, with application to Scanning Imaging Absorption Spectrometer for Atmospheric Chartography (SCIAMACHY), *J. Geophys. Res.*, Vol. 110, D18311, doi:10.1029/2005JD005853, 2005.

5. van Soest G., Tilstra L. G. and Stammes P., Large-scale validation of SCIAMACHY reflectance in the ultraviolet, *Atmos. Chem. Phys.*, Vol. 5, 2171 2180, 2005.

6. Tilstra, L. G. and Stammes P., Intercomparison of reflectances observed by GOME and SCIAMACHY in the visible wavelength range, *Appl. Opt.*, Vol. 45, in press, 2006.

7. Krijger J. M. and Tilstra L. G., Current status of SCIAMACHY polarisation measurements, Envisat Validation Workshop Proceedings, *ESA Spec. Publ. SP-531*, 2003.

8. Tilstra L. G. and Stammes P., Alternative polarisation retrieval for SCIAMACHY in the ultraviolet, *Atmos. Chem. Phys.*, Vol. 5, 2099 2107, 2005.