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Interactive Comment

Interactive comment on "The UV-A and visible solar irradiance spectrum:inter-comparison of absolutely calibrated, spectrally mediumresolution solar irradiance spectra from balloon- andsatellite-borne measurements" *by* W. Gurlit et al.

W. Gurlit et al.

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We are grateful to the overall positive comments and suggestions given by the reviewer. Please find below our point-to-point reactions in italic.

Anonymous Referee 1

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The text clearly explains what is the aim of the article. I express again my initial positive opinion for publication in ACP.
I have some questions and suggestions:

1) Before flight/after flight performances: have you noticed any change concerning the instrument responsivity once the instrument was returned in the laboratory?

Yes, in fact such changes in responsivity were observed but in all cases good reasons to explain them were found.
First changes in the instrument responsivity from flight to flight are rather likely due to the rough landings of larger balloon payloads, which easily may lead to a de-adjustment of the optical set-up.
For example, between the Kiruna 2004 calibration at the ground and the ground-based calibration at Teresina a degradation of the responsivity of the UV instrument was found, which we could clearly trace back to 2 fibre bundles (out of in total 11) broken, during the harsh landing of the payload during the Kiruna campaign. Contrary in the time between the balloon flights conducted from Aire sur l'Adour in Oct. 03 and from Kiruna in March 04, the comparison of the responsivity investigated with PTFE integrating sphere indicated a change in responsivity for the visible instruments of smaller than 1%. Further calibration exercises performed during a field campaign at Teresina in Nov. 04, indicated a change in responsivity (traced wit the sun simulator) by as much as 2%. These changes, however could be traced back to dust (emanated from the poorly cemented floor of the hangar) deposited on the optical parts of the instrument. Cleaning the optical setup regularly, the responsivity changes became much lower (<1%), close to the reproducibility of the measurements in a cleaner environment.

2) Flatfield:
Many instruments have a flatfield dependence of their responsivity. Is this effect could remain despite using the Sun tracker? It is unclear for me if the mirror reflectivity was measured for all angles of incidence as met during the flight? If not, how the reflectivity is taken into account?

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The elevation dependence of mirror reflectivity was investigated by an end-to-end illumination of instrument through the Sun tracker using a homogeneous Sun Simulator beam while tilting the 500 kg heavy gondola into different sun elevation positions (0–10°) with respect to the light beam of the calibration unit. The flat field dependence of the instrument was investigated by illuminating the Sun tracker entrance with the homogeneous Sun Simulator beam while performing an X-Y-scan by adjustments of the Sun Tracker. The resulting change in responsivity was found to be somewhat ambiguous – but small (<1.5%) i.e. no clear dependence with elevation angle was found within the errors of the measurements –. The S/P-polarization and the wavelength-dependent reflectivity of one of the two identical sun-tracker mirrors were also measured in steps of 1° incidence angle on component level by a certified company (SOPRA/Paris) (see Figure 1). From this measurement the throughput of the Sun Tracker for different observation geometries was calculated which combined with the polarization sensitivity of the DOAS instrument resulted in an elevation dependent instrument responsivity of better than 1%. As before, it was found that the reflectivity changed by less than <1% for the relevant angle range (45°–54°), however with a scatter in the data of similar size.
Finally, the wavelength-dependent instrument response was also investigated by theoretical calculations of the polarization dependent Sun tracker throughput for different elevation angles and the measured polarization sensitivity of the instrument (without the Sun Tracker). As for the other tests, the result indicated <1% change in response for the different elevation geometries. Since in all 3 tests the uncertainty in the wavelength dependent reflectivity was found to be small (<1%) or at least smaller than the other errors of the calibration, its was accounted for in the error budget.
In conclusion, even we account the non-linearity seen in the Langley plot to the wavelength and angle-dependent response of the sun-tracker mirrors, the relatively large uncertainty in the latter prevented us to correct accordingly to the Langely plot.

The figure can be found at

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Fig. 1: Wavelength and angle dependence of the mirror reflectivity as measured by SOPRA Paris. The typically angle range for direct sun measurements at balloon float is 45° to 51°.

3) Linearity of the detection
The use of lamps allows calibration of the instrument, that is to say determination of its responsivity. Signal from calibration lamps is usually smaller than the signal from the Sun. Have you verified the linearity of the detection system?

Yes, we are aware of this problem, too. The non-linearity of the detector across the entire dynamic range is caused by (a) the non-linearity of the dark current, (b) the saturation dependent response of the detector and (c) the exposure time.
In our study, we accounted for effect (a) by calculating the dark current using a differential equation derived from the separately measured dark current as function of exposure time and detector saturation (for details see c.f., (a) Stutz, J., Messung der Konzentration troposphärischer Spurenstoffe mittels Differentieller-Optischer-Absorptionsspektroskopie: Eine neue Generation von Geräten und Algorithmen", Ph.D. Thesis Univ. Heidelberg, Heidelberg, 1996. (b) Stutz, J., and Platt, U., "Problems in using diode arrays for open path DOAS measurements of atmospheric species, Proc. EOS/SPIE Symp. Berlin, Optical methods in atmospheric chemistry, vol. 1715, 1992, 329–340, and (c) Ferlemann, et al., Differential Optical Absorption Spectroscopy Instrument for stratospheric balloon-borne trace gas studies, Applied Optics, 39, 2377–2386, 2000). The residual dark current error is accounted in the error budget.
Effect b) was studied by varying the added light of a flat, i.e. only weakly on wavelength dependent light source with light of a source that contains absorption lines of known optical depth (Fraunhofer lines) for typical exposure times in our measurements. No

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sizable effect was found in this case for typical saturation levels of the detector (10–90%). Similar tests of the detector non-linearity for large exposure times (minutes to hours) for varying light intensities are planned in future (effect ©). Finally, the non-linearity of the detector caused from different exposures and saturation levels was also considered in the error budget (see Table 1, line 3).

4) About Table 1
What is contained in "calibration procedure", and what uncertainty is originating from the counting (generally when calibration lamps are used due to the low signal).

The 'calibration procedure' as described above includes the following errors obtained from our measurements:

(a) error due to extrapolation of the FEL NIST reference distance (R=50 cm measured from the front size of the 6 mm FEL filament) to the DOAS to FEL calibration distance (about 3.5 m) caused form the finite sized (6 mm) of the FEL filament (The FEL is not a pint source): 1.2%
(b) error of the distance measurement: 0.5%)
(c) straylight error from background light: 0.5% UV in the 1% visible
(d) error from the alignment of the optical axis of the DOAS visible and UV telescopes with respect to the NIST-FEL lamp: 1.5%
(e) remaining error in the dark current correction: 4.01% @ 340 nm, 1.07% @ 390 nm, 0.83% @ 500 nm, 0.48% @ 600 nm
(f) detector shot noise error:
(g) electronics read out noise: the combined errors for (f)+(g) are 0.0422% @ 340 nm, 0.0151% @ 390 nm, 0.0277% @ 500 nm, and 0.0185 @ 600 nm
(h) detector non-linearity error is estimated to $<$1%.
(i) correction for the optical axis misalignments of the UV telescope for the ASA'03 flight: 2.1% error
(ii) Finally all these errors are Gaussian added for the resulting 'calibration procedure'

errors stated in Table 1 line 3.

Errors arising for an actual balloon measurement are:

(A) Langley correction error 0.51% @ 340 nm, 0.5% @ 390 nm, 0.36% @ 500 nm, 0.36% @ 600 nm
(B) Suntracker mirror reflectivity error, $<$1%
(C) Suntracker pointing errors for the UV/visible instrument are 1.4%/0.1%, respectively

5) Wavelength scale
Have you compared the position of some Fraunhofer lines of your spectrum with position given for example by Kurucz (1984)?

In a first step, we wavelength calibrated our spectrometers with well-known Hg lines (c.f., see Ferlemann et al., 2000 cited in the manuscript). Next we checked by spectral fitting the wavelength scale of our spectra with respect to Kurucz (1984) in selected wavelength intervals. The result is the following: (Center wavelength nm/shift in nm): 323.3/$-$5.379e-02$\pm$6.696e-03, 340.0/1.347e-02$\pm$8.494e-03, 360.1/1.835e-02$\pm$6.529e-03, 380.2/1.278e-01$\pm$7.420e-03, 400.4/2.671e-01$\pm$7.384e-03427.1/$-$2.231e-01$\pm$1.050e-02, 481.2/3.227e-02$\pm$2.368e-02, 535.5/3.491e-02$\pm$2.118e-02, 589.4/1.261e-02$\pm$2.600e-02, 634.5/1.520e-02$\pm$6.392e-02,

6) Table 3
I have calculated the energy from 325 to 650 nm for your spectrum, Kurucz and SOLSPEC. The difference Kurucz to SOLSPEC is small (1.6 W/m^2), but greater with your spectrum. This suggests (as well as Table 3) a greater irradiance in the visible range. Could you explain/comment this result, in particular taking into account a better precision in that domain as given in Table 1?

Thanks to your hint we identified a bug (in the dark current and offset correction of the

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detector), and which led us to revise our results from the previous manuscript. The new result is the following:
(1) When integrating over the 4 band mentioned in table 3, our spectrum vs Kurucz now yields 502.54 W/m^2 vs 503.07 W/m^2 or $-$0.53 W/m^2 ($-$0.1%)
(2) Compared to Kurucz (and to SOLSPEC), our spectrum shows (a) a slightly smaller UV-A (325–370 nm) spectral irradiance ($-$1.81 W/m^2, or $-$3.8%),
(b) a larger spectral irradiance (+0.9 W/m2 or, +0.3%) in the 435–585 nm wavelength band and again a smaller irradiance ($-$0.83 W/m^2 or $-$0.7%) 585–650 nm visible wavelength band in broad agreement with SCIAMACHY, SOLSPEC and SIM
(3) Also as far as we know Kurucz to SOLSPEC are cross-calibrated and therefore a smaller discrepancy than to all other spectra is expected.

7) Summary of differences between spectra
In the abstract, you give the differences between the spectra that you have considered in this study. A Table summarizing these differences would be welcome at the end of the paper. This would allow to examine if the reported differences are consistent with the quoted accuracy of each spectra used for comparison.

In the revised manuscript, in Table 3 we added (relative) discrepancies of the individual spectra, relative to Kurucz et al.

8) About the range 325–370 nm, a 5% difference is found by SCIAMACHY and DOAS (as well as with Neckel and Labs, 1984) with respect to MODTRAN and SOLSPEC. However, the same difference is shown with data taken from space by SSBUV and SOLSTICE with respect to Neckel and Labs. You also report that such a difference exists with the recent Harrison spectrum (2003). This spectrum is obtained from ground, and in the range 325–370 nm, corrections are important and may induce some error.

We totally concur to your statement!

This is why this spectrum may contain similar features as Neckel and Labs (1984). This point should be discussed as well as the SSBUV and SOLSTICE results.

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In the revised manuscript a comparison with SIM/SOURCE will be included and discussed.

About recent spectra, SOLSPEC has been up dated in 2003 and 2004.

Prior to publication we contacted (Dec. 18, 2003) the principle investigator of SOLSPEC for getting the most recent SOLSPEC data, and hopefully the latest version of the SOLSPEC are included our study.

Interactive comment on Atmos. Chem. Phys. Discuss., 4, 8439, 2004.

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