SCIAMACHY SOLAR IRRADIANCE VALIDATION USING RADIOMETRIC CALIBRATION OF BALLOONBORNE SPECTROMETERS

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ABSTRACT

Solar occultation measurements of balloonbome LPMA (Limb Profile Monitor of the Atmosphere, a Fourier-Transform IR spectrometer) and DOAS (Differential Optical Absorption Spectroscopy, a two channel UV-VIS grating spectrometer) instruments are used for the validation of the SCIAMACHY level-1 product solar irradiance in this “added value” approach. Their primary objective is to measure trace gas concentrations. LPMA [1] and DOAS [2] are mounted on the same gondola and use the same entrance optics to track the solar disc from a stratospheric observation position during sunrise or sunset. As a result of the high float altitude (32 km and more) of the payload, only few corrections (mainly ozone) are needed for atmospheric absorbers, to compare the spectra with the (extraterrestrial) spectra from SCIAMACHY. In order to get absolute measurements of the solar irradiance, the balloon instruments have to be radiometrically calibrated before each flight. This is done on site during the campaigns by using NIST- traceable calibration sources. New optical designs implemented in the calibration sources enable a repeatability of better than 1% even under field conditions.

1. GENERAL

SCIAMACHY on ENVISAT is a spaceborne atmospheric chemistry instrument. Measurements of the absorption, reflection and scattering characteristics of the atmosphere are made in 8 spectral channels from 240 to 2380 nm wavelength. Scattered sunlight is measured in nadir and limb geometry, transmitted solar and lunar radiation in occultation geometry, and solar and lunar irradiance in occultation. For each orbit the solar occultation measurements, including measurements of the solar irradiance, are made during sunrise. All measurements are converted to provide information about the amounts and distributions of selected atmospheric constituents (O_3, BrO, OCLO, SO_2, NO, NO_2, H_2O, CO, CO_2, CH_4, N_2O among others), as well as information about aerosol, pressure, temperature, radiation field, cloud cover, cloud top height and surface reflectance. ENVISAT was launched on 28 February 2002 from Kurou using an Ariane-5 launcher.

2. CALIBRATION SOURCES & PROCEDURES

Prerequisite for the validation of the SCIAMACHY level-1 quantity solar irradiance is a radiometric calibration of the balloon borne LPMA and DOAS spectrometers before each flight. As the integration of the various components (suntracker, LPMA, DOAS, gondola) takes place on site during the campaign, the preflight calibration also has to be made in the field. This requires the setup of an optical metrology lab on site. On the Envisat validation high-latitude campaign taking place in march 2003 from Kiruna (Sweden), a NIST irradiance standard and a newly developed collimated source were used to radiometrically calibrate the LPMA/DOAS payload. Due to the operating principle of the two spectrometers, the calibration approach and the sources and optical setups used were different for each of the two instruments.

The interferometric principle of the FTIR spectrometer requires a collimated optical input. A collimated source, in general, should produce the same results when used at various distances from the target, taken aside the ambient absorptions on the lightpath between source and target. The DOAS spectrometer can be calibrated with a point source, whose intensity depends on the distance between lamp and spectrometer (inverse square law). Both sources, the procedures used, and the results are described below.

Calibration of the FTIR spectrometer LPMA

A collimated source using 1000 watts of inicial optical power and beam forming with mirror optics was specially developed for this purpose (fig. 2). This source simulates a solar disc that appears at a viewing angle of 0.54 ° for the instrument to be calibrated. It produces a highly uniform light beam, whose cross section can be seen in fig. 2. The uniform beam diameter is 16 cm at 2 meters distance from the source.

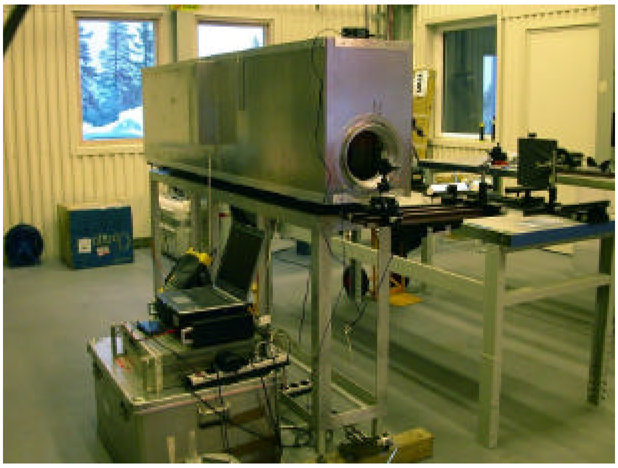

Fig. 1: Irradiance Stimulator for ballonborne LPMA-DOAS

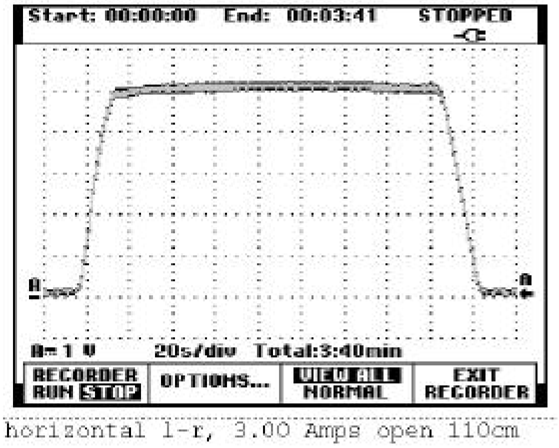

Fig. 2: Beam cross section of irradiance stimulator

Usable radiation is produced from the UV (300 nm) to the IR beyond 3000 nm with a high stability of better than 0.5 %. As a result of the collimated beam, the distance between source and target is not critical. At 1.7 m distance between the source and the LPMA´s optical input, a variation of this distance of +-0.5 m produced a change in the readings of the LPMA of well below 1%. Optical output is sufficient to operate the LPMA in flight-gain during the calibration.

At this point, the apparatus is absolutely characterized (NIST-traceable) for the UV and the VIS part of the spectrum. The characterization of the NIR and IR parts of the spectrum are scheduled for July-August 2003, when transfer equipment for these longer wavelenghts has been set up in our calibration lab. The work done so far shows very stable and reproducible operation of better than 1 % of the LPMA spectrometer, and the calibration source.

Calibration of the DOAS spectrometer

The DOAS spectrometer does not require a collimated optical input. In this case, a NIST standard lamp (1000 watts QTH quartz tungsten halogen) was used as a radiation source. The optical axis of the LPMA-DOAS (defined by the positioning of the sun-tracker) was aligned with the NIST lamp (center of filament) using an alignment fixture as recommended by NIST. The lamp was mounted on an optical rail of 3 meters length, in the center of the field of view of the DOAS. Thus the lamp could be moved on the optical axis of the spectrometer, to produce different intensities according to the inverse square law (see fig. 3, next page). The inverse square law states that the intensity *E* per unit area varies in inverse proportion to the square of the distance X from source to target. This distance, in many cases cannot be measured directly using e.g a ruler, but it can calculated according to

$$X = [d_1 (E_1/E_2)^{1/2} – d_2] / [1- (E_1/E_2)^{1/2}]$$

where d_1 and d_2 are two known variations of the distance measured relatively to point X, and E_1 and E_2 are the intensities (instrument readings) corresponding to these variations. Applying this relationship, measurements of the spectrometer´s output signal at varied distances from the source, which is moved in z-direction on the optical axis, can be used to calculate the absolute distance between source and target for one given point X on the z-axis. Spectra recorded with the calibration source at that point X are then used for the absolute radiometric calibration of the spectrometer. However, the inverse square law for calculating X from the measurements as described holds true only if three conditions are satisfied:

1-The lightsource is small enough to be treated as a **point source**, not an area source. While in general practice, this condition is satisfied when the distance between source and target is equal or greater than five times the largest dimension of the lightsource (filament length, NIST uses a factor of even 15), for the case of the DOAS spectrometer calibrated here, the relatively narrow field of view of the optical telescopes used is an additional limiting factor. The lightsource can only be treated as a point source when the filament is completely inside *the center* of the field of view (3° FOV for the UV channel, with an intensity distribution similar to a Gaussian). For the DOAS UV channel, this requires a minimum distance of approximately 2 meters, with the consequence of low intensity and relatively long integration times for the DOAS.

2-The **optical axis** of the instrument to be calibrated (field of view) must be well known. If, while the lamp is moved in z-direction to take measurements at various distances, this movement does not take place exacly on the optical axis, an error (for the distance measurement) is introduced, because the lightsource does not appear in the center of the instrument´s field of view.

Unfortunately, due to its limited dynamic range, the suntracker of the LPMA-DOAS gondola was not able to lock on our calibration source like it would do during stratospheric float with its solar target. For this reason, the optical axis of each of the two DOAS telescopes (UV and VIS) was found by maximising the instrument´s output signal with manual movements of the suntracker´s mirror.

3-Linearity of the instrument to be calibrated. If the instrument´s response to the incoming radiation is not completely linear, an additional error is introduced in the distance measurement. During our test series the DOAS showed some linearity problems for very short integration times, which seem to be caused by a constant timing offset which is always added to the specified integration time in the readout cycle of the DOAS´ CCD sensor. This is cumbersome, because the calibration measurements on the ground have to use long integration times (500 sec.) to satisfy condition #1 (see *sources and procedures*), while the solar occultation measurements from the stratospheric float position use a much shorter integration time (150 msec.) because of the high level of UV radiation. An additional parameter limiting the accuracy so far is a nonlinearity of the dark current. These parameters are under investigation in order to develop correction algorithms, and to remove systematic effects from our data sets.

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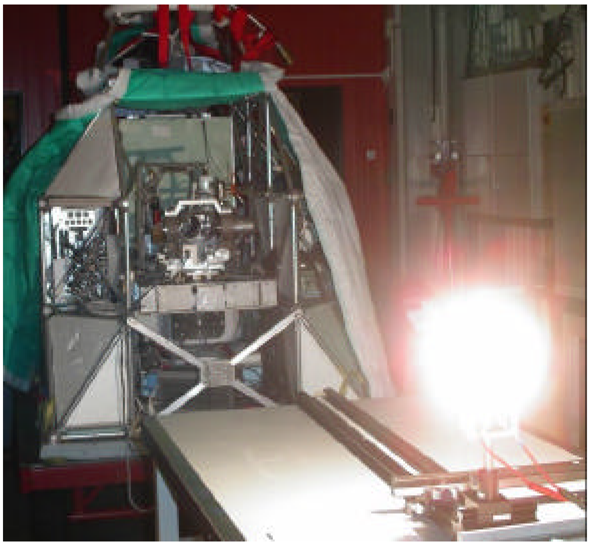

Fig. 3: Absolute calibration of DOAS with NIST irradiance standard

3. RESULTS

Using the inverse square law and the procedure described above, preflight calibration measurements were taken at 6 distances with a stepwidth of 0.5 meters for the UV and the VIS channel, respectively. The result of these measurements, the instrument´s response to a fully characterized NIST irradiance standard at a known distance between source and target, was then used to calculate the radiometric calibration of the DOAS UV and VIS channel. During the measurements it was found out that the DOAS telescopes were not perfectly aligned with the suntracker. This means, that during the flight, the suntracker´s automatic tracking mode would not provide maximum signal for the DOAS telescopes, though it would do so for the LPMA spectrometer. To quantify this systematic pointing error, additional measurements with the collimated source (solar simulation) were undertaken. From these measurement, a wavelength-independent gain correction factor was derived and applied for the DOAS data. A comparison of the various solar irradiance measurements made by us, and from other sources, can be seen in fig . 4 (next page)

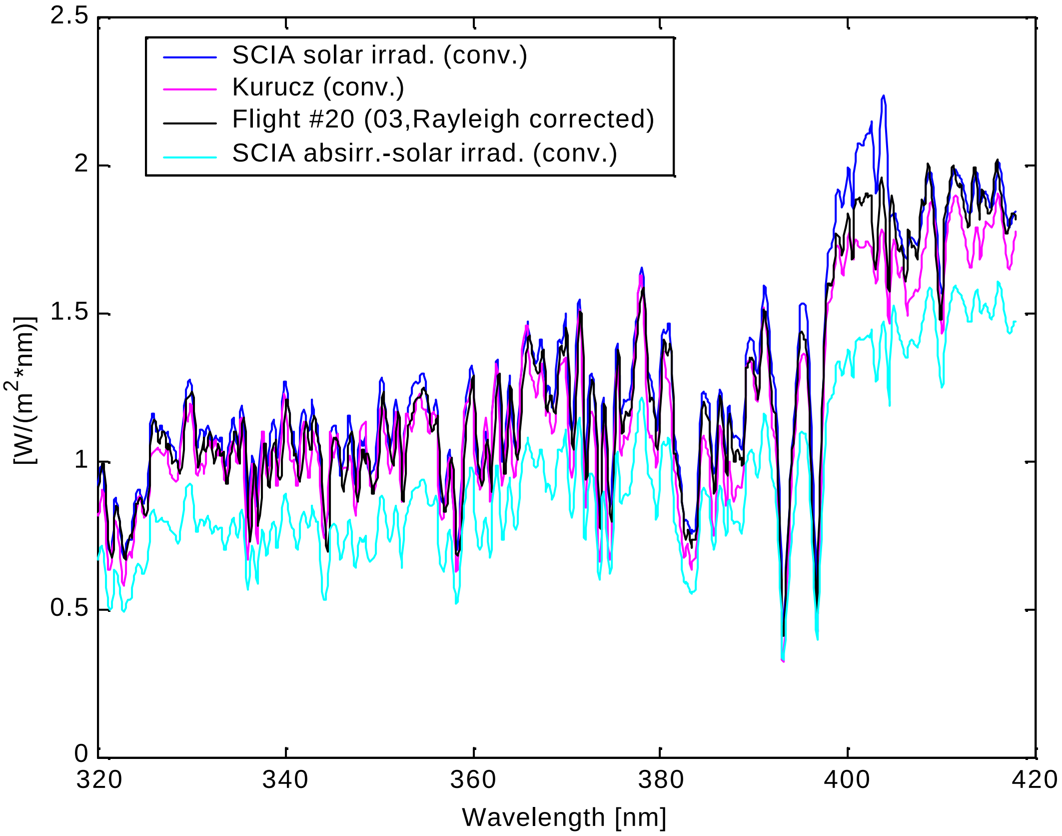

Fig. 4: Solar irradiance measurements by SCIAMACHY, Kurucz, and balloon-borne DOAS (UV)

The data shown should be regarded as preliminary. They offer a first look at the SCIAMACHY and the DOAS solar irradiance measurement for the time being. There remain open a number of questions to be answered later after more detailed studies of DOAS, LPMA and SCIAMACHY data and full understanding and application of all error correction terms. The various UV solar irradiance measurements have been convoluted to uniform spectral resolution.

The data shown are:

1) A SCIAMACHY spectrum, irradiance calculated from radiance calibration data by TPD-TNO.
2) The Kurucz solar spectrum (Kitt Peak)
3) A DOAS UV spectrum calculated from LPMA DOAS flight # 20 (Kiruna, spring 2003)
4) A SCIAMACHY irradiance spectrum (20-30% low), from irradiance calibration data by TPD TNO

The original SCIAMACHY irradiance calibration by TPD TNO (lower trace) seems to produce solar irradiance results that are about 20-30 % too low. In an additional approach, irradiance data wer calculated from radiance data and the SCIA slit function by TPD-TNO (upper trace). The other two traces in fig. 4 are the Kurucz (Kitt Peak) spectrum and the DOAS spectrum of flight #20 (Kiruna, spring 2003).

4. ERROR BUDGET

The results shown here (LPMA-DOAS results as well as SCIAMACHY results) are still preliminary. It seems that at least for the DOAS the majority of the sources of uncertainty have been understood by now, but at the time of writing, not all corrective terms have yet been applied. Furter investigation including lab measurements on the DOAS spectrometer are underway in order to reduce and to better quantify the error budget in our data set. In general, the errors can be classified into three types:

1. Uncertainty of the irradiance standards used, defined by NIST. These can hardly be reduced. Depending on the wavelength, they are on the order of 1%. However, we use exactly the same standards (the particular units, F-455, F-456) that were used for SCIAMACHY radiometric calibration. For comparison with SCIA level-1b data, thus these errors should appear as systematic errors.

2. NIST standard drift and ageing error, specified as max. 0.5 % per 24 hours operation time
3. Uncertainty through positioning errors in optomechanical setup, errors in operating condition of standard lamps e.g temperature / current errors. These errors can be quantified as 1%, which is well acceptable.
4. Errors that appear by not completely satisfying the inverse square law (see above, points 1-3, *sources and procedures*). These errors are mostly related to non-perfect behaviour of the DOAS spectrometer (linearity errors, 3 %) and difficulties in defining / reproducing of the optical axis (1 %). However, as these errors are at least in part systematic (linearity error, integration time error) we expect to reduce these errors to well below 5 % for existing data and even further for data acquisition on future campaigns.

5. CONCLUSION

Balloon borne grating spectrometers and a Fourier-Transform spectrometer have been radiometricalliy calibrated on the campaign site in Kiruna before launch in order to measure spectrally resolved solar irradiance. This quantity is used for comparison with the corresponding data of the SCIAMACHY spectrometer onboard the ENVISAT satellite. For the satellite instrument as well as for the balloon borne instruments, data processing is still underway, and only first (preliminary) results are shown here. Absolutely calibrated solar irradiance in the UV acquired with the DOAS grating spectrometer suggest that the corresponding data from SCIAMACHY might be on the order of 5 % too high, or 20-30 % too low depending on the SCIAMACHY dataset used. This agrees with similar findings by [3]. Final results will be ready in summer 2003.

6. ACKNOWLEDGEMENT

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7. REFERENCES

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