AIP | Conference Proceedings

A guide to measuring solar UV spectra using array spectroradiometers

Mario Blumthaler, Julian Gröbner, Luca Egli, and Saulius Nevas

Citation: AIP Conf. Proc. **1531**, 805 (2013); doi: 10.1063/1.4804892
View online: http://dx.doi.org/10.1063/1.4804892
View Table of Contents: http://proceedings.aip.org/dbt/dbt.jsp?KEY=APCPCS&Volume=1531&Issue=1
Published by the AIP Publishing LLC.

A Guide to Measuring Solar UV Spectra using Array Spectroradiometers

Mario Blumthaler[a], Julian Gröbner[b], Luca Egli[b] and Saulius Nevas[c]

[a]Medical University Innsbruck, Biomedical Physics, Müllerstr. 44, A-6020 Innsbruck, Austria
[b]Physikalisch-Meteorologisches Observatorium Davos, World Radiation Center, Davos Dorf, Switzerland
[c]Physikalisch-Technische Bundesanstalt, Braunschweig and Berlin, Germany

Abstract. Array spectroradiometers are cost-effective instruments allowing fast measurement sequences to monitor the high variability of solar radiation. From the spectra any desired biologically weighted doses within their operational spectral range can be derived by post-processing. Therefore, array spectroradiometers have the potential to replace filter radiometers currently used in UV monitoring networks. However, they suffer significantly from stray light. Thus for routine operation it is important to follow strict procedures for characterisation, operation and data post-processing, which are suggested in these guidelines. The most important characteristics of array spectroradiometers are wavelength calibration, slit function, stray light properties, spectral structure of the dark signal, linearity, noise equivalent irradiance and spectral responsivity. For routine operation, temperature stabilization is absolutely necessary as well as automated dark signal measurements. Integration time and number of repetitions control the noise level and they have to be defined according to the measurement requirements. Data post-processing includes consideration of nonlinearity, dark signal with its spectral structure, integration time, stray light correction, spectral response function and weighting function.

Keywords: Solar UV radiation, Array spectroradiometers, Stray light, Noise equivalent irradiance.
PACS: 92.60.Vb, 07.60.Rd

INTRODUCTION

This guide is intended to summarize the requirements when making routine measurements of global irradiance of solar UV radiation using array spectroradiometers. So far in many networks world-wide broadband or filter radiometers are used for routine measurements and in a few cases scanning spectroradiometers are operated. The latter have the great advantage to provide full information about the solar spectrum allowing determination of dose rates for any biological weighting function (i. e. action spectra for erythema or Vitamin D synthesis), whereas this information can be derived from broadband or narrow band filter radiometers only with very limited accuracy. However, scanning spectroradiometers are very expensive and need a skilled operator for maintenance. The recently developed array spectroradiometers offer an opportunity to utilize the advantages of the scanning spectroradiometers and still have a reasonable price. Also very fast data acquisition is now possible and maintenance is less demanding because array spectroradiometers do not have moving parts and therefore they are quite robust. However, array spectroradiometers are only single monochromators and therefore suffer significantly from stray light, biasing irradiance measurements typically in the UV-B wavelength range. This is a severe problem for measurements of solar UV radiation due to the sharp cut off of the solar UV spectrum as a consequence of ozone absorption. Therefore, it is important to follow strict procedures when using array spectroradiometers for measuring spectral solar UV radiation in order to achieve the desired quality of the results. The guidelines presented here are relevant for the application of array spectroradiometers for routine observations, where the main aim is not the investigation of the spectral structure of the solar spectrum but the determination of weighted dose rates. An assessment of the uncertainty is beyond the scope of these guidelines and will be treated in a separate paper.

Greater details about background information, instrument characterisation and general guidelines can be found in GAW-report No. 191 “Instruments to measure solar ultraviolet radiation – Part 4: array spectroradiometers” [1].

In the following chapters, suggestions are given for requirements and characterisation of array spectroradiometers, for the measurement procedure itself and for post processing of the raw data to derive the final products.

REQUIREMENTS AND CHARACTERIZATION

The detection threshold for array spectrometers is defined and justified in [1] to be 1 $mWm^{-2}nm^{-1}$. This means that the noise equivalent irradiance (NEI, standard deviation of the dark measurements divided by the instrument's

Radiation Processes in the Atmosphere and Ocean (IRS2012)
AIP Conf. Proc. 1531, 805-808 (2013); doi: 10.1063/1.4804892

responsivity) should be smaller than 1 $mWm^{-2}nm^{-1}$. The NEI decreases with increasing integration time (Fig. 1), for several investigated array spectroradiometers almost as a linear function. Therefore, for reducing the noise level of a measurement over a given time interval it is more efficient to increase the integration time (as long as overexposure is avoided) than to carry out more repetitions (where the noise level is only reduced proportionally to the square root of the number of repetitions). Furthermore, the NEI can be reduced by cooling the detector.

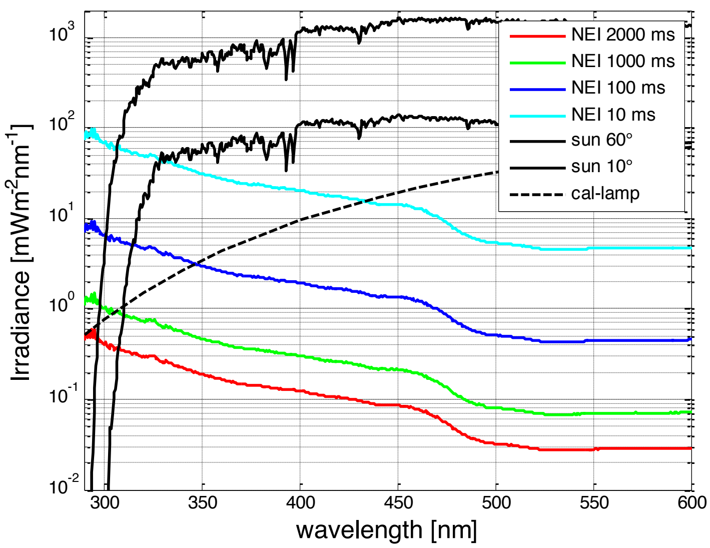

FIGURE 1. Noise equivalent irradiance (NEI) for different integration times (10 ms to 2000 ms). Typical solar spectra for 10° and 60° solar elevation and spectrum of a 1000 W calibration lamp.

The NEI is a limiting factor for the overall uncertainty of a measurement. The comparison of the NEI with typical solar spectra and a calibration lamp (Fig. 1) especially in the UV region demonstrates the clear necessity to keep it as low as possible. By applying a Monte Carlo technique it was calculated that in order to achieve an uncertainty of the erythemally weighted irradiance of 1% (where the array detector noise is assumed to be the only source of uncertainty) the NEI should not be larger than 1 $mWm^{-2}nm^{-1}$ for solar zenith angles above about 60°, especially under high ozone concentrations (Fig. 2).

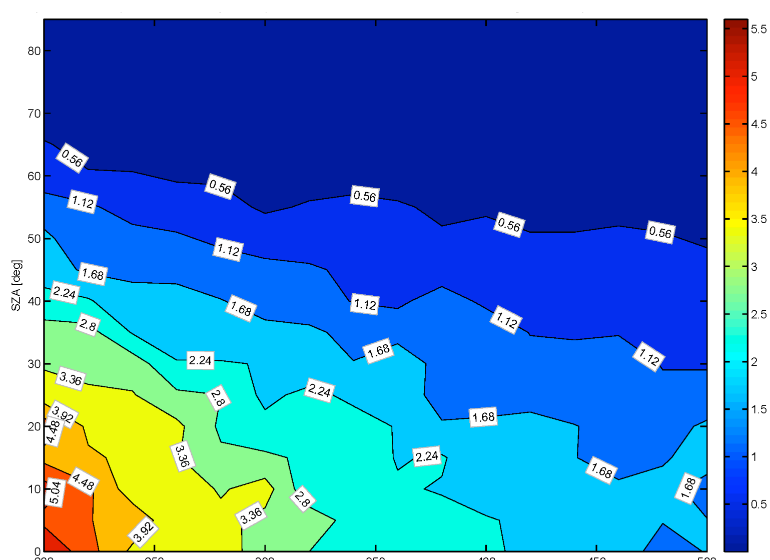

FIGURE 2. Noise equivalent irradiance required to measure erythemally weighted solar irradiance (dependent on total ozone amount (x-axis) and solar zenith angle (y-axis)) with an uncertainty of 1%, if this would be the only source of uncertainty.

For most commercially available array spectroradiometers temperature stabilisation is necessary because the dark signal depends in a very sensitive way on the temperature of the array detector and also wavelength and irradiance calibrations depend on temperature. Additionally, the instruments' temperature may increases due to operation. These dependences are very complex and therefore it is very difficult to apply a correction for temperature variations. The degree of stabilisation will intimately depend on the hardware design of the instrument and on the possible use of a detector-cooling. For some instruments it might be necessary to achieve a level of stabilization in the order of 0.1° to avoid negative effects of temperature variations.

As the dark signal should be determined for each measurement, it is necessary to use a setup with an automated shutter controlled by the operating computer.

The connections of the quartz fibre to the input optics on the one hand and to the instrument on the other hand have to be very reproducible, because even very small variations of these connections will have a significant effect on the responsivity of the array spectroradiometer [2]. It would be best not to disconnect the fibre after characterisation and calibration of the instrument.

Stray light is the most stringent characteristic when using array spectroradiometers for measuring spectral solar UV irradiance. Instruments available at the moment need further data post-processing by applying suitable stray light correction algorithms [3, 4]. Of course, the better the stray light suppression within the array spectroradiometer is achieved, the smaller the necessary correction and thus the smaller the remaining uncertainty. According to [1], the final data should not be affected by stray light levels more than 1 $mWm^{-2}nm^{-1}$.

The determination of the characteristics of the array spectroradiometer has to be carried out before the instrument is set up for routine measurements and should be repeated regularly. This holds especially for:

- *wavelength calibration*: relation between pixel number and wavelength
- *slit function*: full width at half maximum and shape of the function (i.e. at 10^{-3} of the peak)
- *stray light* over the whole spectral range of the array detector (near and far field stray light)
- *spectral structure of the dark signal*: the dark signal may have a specific structure in dependence on wavelength, which can be determined once with high accuracy and then applied during post processing. This structure may also depend on the selected integration time and on the temperature of the instrument
- *linearity* with two components: radiometric (of the photon detector, determined by varying the incoming intensity) and data acquisition related (determined by variation of the integration time for a fixed intensity)
- *irradiance calibration* (spectral responsivity). When a calibrated lamp is used then also for this measurement the appropriate data post processing has to be applied, especially the stray light correction algorithm
- *noise equivalent irradiance* in dependence on integration time
- *settling time* when changing the integration time: for some instruments this can be up to one minute for large differences between the integration times
- *blooming effect* in case of overexposure (in particular for CCD detectors).

MEASUREMENT SCHEDULE

Depending on the focus of the solar measurements, several modes of operation are possible. For each mode it is necessary to carry out a dark measurement, as the dark signal might vary during operation time of a day.

- *continuous*: fixed integration time, as many repetitions as possible during one minute; result as mean value and standard deviation of the mean over one minute
- *discrete*: autorange of integration time by making first a test measurement with a short integration time and then calculating the optimum (maximal possible) integration time to avoid overexposure. Possibly a significant waiting time is necessary when changing the integration time. Repetition at fixed time intervals (i.e. 5 min)
- *highest accuracy*: autorange and overexposure. After a first measurement according to the discrete mode, an additional measurement is carried out with an increased integration time by i.e. a factor of 10. Needs sophisticated procedures to combine the two measurements, but yields highest accuracy. Special care has to be taken to discriminate between the saturated and valid parts of the measured spectrum as adjacent pixels to the saturated pixels can be affected (blooming).

DATA POST-PROCESSING

- *Rawdata:*
  counts and wavelength(pixel); additional information: time of measurement, integration time, number of measurements, dark signal, temperature

- *Lev1data:*
  correction for radiometric nonlinearity
  subtraction of the dark signal (including its spectral structure) from the measured signal
  normalisation with integration time, result in counts per sec
  correction for nonlinearity of data acquisition system (integration time)
- *Lev2data:*
  in-range stray light correction (still pixel-based)
- *Lev3data:*
  calibration applied, result in $mWm^{-2}nm^{-1}$
- Weighting with biological action spectrum and integration, resulting to biological dose rate

When a measurement of the reference lamp is carried out for the determination of the irradiance calibration then all steps up to the lev2data are necessary, before the responsivity can be calculated based on the lamp certificate.

An example of the final result for measurements of erythemally weighted solar irradiance on a clear day using an array spectroradiometer is given in Fig. 3. This result is compared with simultaneous measurements using a scanning double monochromator. The agreement over the whole dynamic range of a day is very satisfying.

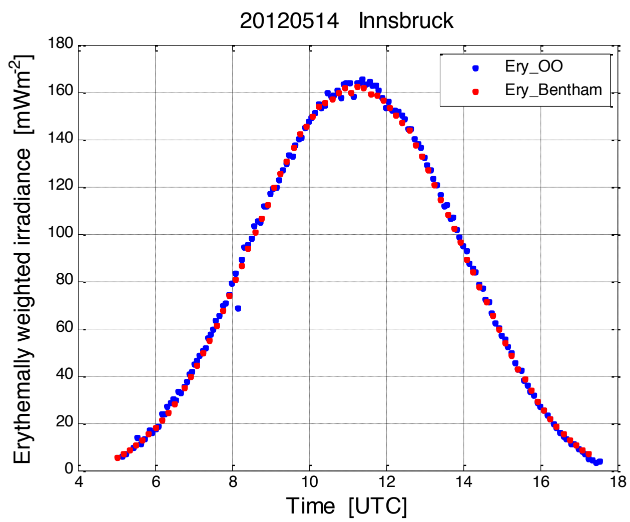

FIGURE 3. Erythemally weighted irradiance measured during a clear day in Innsbruck, Austria, with an array spectroradiometer (Ocean Optics USB4000) every 5 minutes (blue points) and with a collocated Bentham DTM300 every 10 minutes (red points).

ACKNOWLEDGMENTS

This guide was compiled within the EMRP ENV03 Project "Traceability for surface spectral solar ultraviolet radiation". The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union.

REFERENCES

1. G. Seckmeyer, A. Bais, G. Bernhard, M. Blumthaler, S. Drüke, P. Kiedron, K. Lantz, R. McKenzie and S. Riechelmann, "Instruments to measure solar ultraviolet radiation Part 4: Array Spectroradiometers" WMO/GAW No.191, World Meteorological Organization, Geneva, 2010.
2. S. Nevas, A. Teuber, A. Sperling and M. Lindemann, *Metrologia* **49**, S48-S52 (2012).
3. A. Kreuter and M. Blumthaler, *Rev. Sci. Instrum*. **80,** 096108 (2009).
4. S. Nevas, G. Wübbeler, A. Sperling, C. Elster and A. Teuber, *Metrologia* **49**, S43-S47 (2012).