WORLD METEOROLOGICAL ORGANIZATION
GLOBAL ATMOSPHERE WATCH

GAW No. 112

ADDENDUM

WMO/STUK ’95 Intercomparison
of Broadband UV Radiometers:
A small-scale follow-up study in 1999

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1. INTRODUCTION

In 1995 the Finnish Centre for Radiation and Nuclear Safety (STUK) organized in cooperation with the University of Innsbruck the first global intercomparison of broadband radiometers, *The WMO/STUK '95 intercomparison of erythemally weighted solar UV radiometers* (Leszczynski et al. 1997, Leszczynski et al. 1998). The main objective was to decrease the difference between scales of broadband solar UV measurements carried out by UV-monitoring networks around the world. Altogether 20 erythemally weighted radiometers were tested in laboratory and calibrated in solar radiation against two well-characterized spectroradiometers. The majority of the broadband meters (15) were Solar Light Model Model 501 (denoted SL 501) radiometers. The small-scale follow-up study in '99 was arranged to either confirm stability or to reveal drifts of the broadband meters.

In 1999, two of the SL 501 meters included in the WMO/STUK '95 intercomparison were re-tested and re-calibrated in Finland by STUK in the same location as in 1995 and using the same test methods as in 1995. In 1999, the same meters were calibrated and tested also in Greece by the University of Thessaloniki (UTH) in co-operation with the University of Innsbruck (ATI) (Bais et al. 2000).

The WMO/STUK '95 intercomparison as well as the small-scale follow-up intercomparison in 1999 were partially supported by the World Meteorological Organization (WMO).

2. LOCATION AND CONDITIONS

During the solar calibrations at STUK in Helsinki in 1995 and 1999, the measurements were carried out in the same location, on the roof of a measurement cabin mounted on the roof of the five-storey office building of STUK in Helsinki (60.2 ^{o}N, 25.0 ^{o}E, 0 m a.s.l.), Finland. The horizon was practically unobstructed. The only minor obstruction was a radio mast in south-west, which did not disturb the intercomparisons. During the measurements the cloud indices were 0/8…2/8 in 1995 and 0/8 in 1999, and all the results are based on measurements when the sun itself was not obstructed with the clouds. During the campaigns, the total ozone values varied from 315 to 370 DU and from 307 to 308 DU in 1995 and 1999, respectively.

3. MATERIALS AND METHODS

Materials and methods applied for meter characterisations at STUK in 1999 were same as in 1995 (Leszczynski et al., 1997, Leszczynski et al., 1998), except for the reference spectroradiometer. When the new reference spectroradiometer, Bentham DM 150 had been taken into use in 1996, the continuity of the traceability of the solar UV measurements by STUK had been thoroughly verified by simultaneous calibrations and solar measurements with the previous reference spectroradiometer, OL 742. Besides this change in instrumentation, also a new method described in *Chapters 3.3.3* and *3.3.4* was applied for the solar calibration of the broadband meters in 1999. Materials and methods applied in Greece in 1999 are described elsewhere (Bais et al. 2000).

3.1 The reference spectroradiometers in 1995 and 1999

Two double-grating reference spectroradiometers, the OL 742 spectroradiometer of STUK and the Bentham DM 150 of ATI participated in the WMO/STUK intercomparison '95. The agreement between the DM 150 of ATI and OL 742 of STUK was within ± 5%. An overall uncertainties of the solar UV measurements with the OL 742 of STUK and DM 150 of ATI were estimated as ± 8% (2σ) and ± 6 %, respectively. Numerical corrections were applied to minimize the errors caused by cosine response, shift of the wavelength scale and in the case of OL 742 temperature sensitivity of the optics head (Leszczynski et al. 1997, Leszczynski et al. 1998).

In 1999, the STUK Bentham DM 150 spectroradiometer (taken into use in 1996, see section 3) served as the reference instrument. The agreement of the OL 742 and this new reference spectoradiometer was within ± 2%. Previously, an uncertainty as low as ± 6% has been reported for the solar measurements with the DM 150 (Jokela et al. 2000). However, after the 1999 measurements, it appeared that the measured irradiance values during the solar calibrations had been too high by approximately 5% due to an unpredicted performance of the photomultiplier tube. After correcting for this systematic source of uncertainty by dividing the spectral data by a factor of 1,05, the uncertainty of the spectroradiometric solar UV measurements is estimated to be ± 8%.

3.2 Broadband radiometers

The erythemally weighted radiometers tested in 1995 by STUK and ATI, and in 1999 by STUK, ATI and UTH were two SL 501 meters, # 635 of STUK and # 1466 of the Finnish Meteorological Institute.

3.2.1 Dark room measurements

In 1999, the laboratory tests at STUK were carried out in the same dark room as in 1995 using exactly the same equipment and methods as in 1995 *(Leszczynski et al., 1997, Leszczynski et al., 1998)*. As in 1995, laboratory tests included measurements of cosine and spectral responsivities and a halogen lamp measurement. An irradiance monochromator, consisting of a 1000 W xenon lamp Oriel 6271 and a monochromator Oriel 77200, was used for the spectral responsivity measurements. The cosine response measurements were carried out having a solar radiation simulating filtered metal halide lamp Philips HPA 400 W as the radiation source. Quartz-halogen FEL standard lamps of 1 kW were used for calibrations of the spectroradiometers and also for the stability tests of the broadband meters.

Halogen lamps were operated by utilizing an Optronic OL 83DS Precision Current Source. A shunt resistor (Cambridge Instruments 10 mΩ Manganin No L-201388) together with a Keithley 182 Sensitive Digital Voltmeter were used to monitor the lamp current. The shunt resistor and voltmeter are calibrated at the National Standards Laboratory of Finland. The estimated uncertainties of the resistance and Keithley 182 voltmeter are ± 0.005% and ± 0.001%, respectively. The voltage drop across the lamp was monitored with a Keithley 196 Digital Multimeter.

3.2.2 Solar calibrations

The calibration measurements in solar radiation were carried out at solar elevation angles from approximately 10° to 53° and from 25° to 53° in ’95 and in ’99, respectively. During the measurements the optical axis of each instrument was directed towards the zenith.

From the spectral measurements the dose rate value was derived by computing the erythemally effective irradiance by convolving the solar irradiance with the CIE action spectrum (McKinlay and Diffey 1987) in the range of from 290 to 400 nm and converting the irradiance to dose rate (1 MED/h = 210 J/m^2h = 0,0583 W/m^2).

In ’95, the instantaneous readings of the broadband radiometers were recorded simultaneously within the range 290 to 330 nm of the spectral scan, and the average of the readings recorded simultaneously with the spectroradiometer wavelengths of 290, 300, 310, 320 and 330 nm was calculated and compared with the dose rate values based on the spectroradiometric measurements.

In ’99, the broadband meters were operated using a 1 min recording interval and the CIE-weighted spectroradiometric solar measurement data was used to calculate weighting factors for the simultaneously recorded broadband data. The weighted time averages of the broadband data were compared with the spectral data.

The agreement between the methods applied in ’95 and ’99 is estimated to be better than 1% for measurements when the sun is not obstructed by clouds.

3.2.3 Calibration factors

To be able to compare the '99 data with the '95 results, the calibration factors (CF's) were determined similarly as in '95, having the CIE action spectrum for erythema (McKinlay and Diffey 1987) as reference. CF's were calculated as a ratio of the CIE-weighted dose rate derived from the spectral irradiance measurements of the range 290 to 400 nm with the spectroradiometer to the dose rate values of the test meters. In '95, the uncertainty of the spectroradiometric calibration of the broadband meters under the prevailed atmospheric conditions was estimated to be ± 10%. In '99, however, the uncertainty is estimated to be slightly higher, ca. ± 12% due to the peculiar behaviour of the photomultiplier tube of the Bentham DM 150.

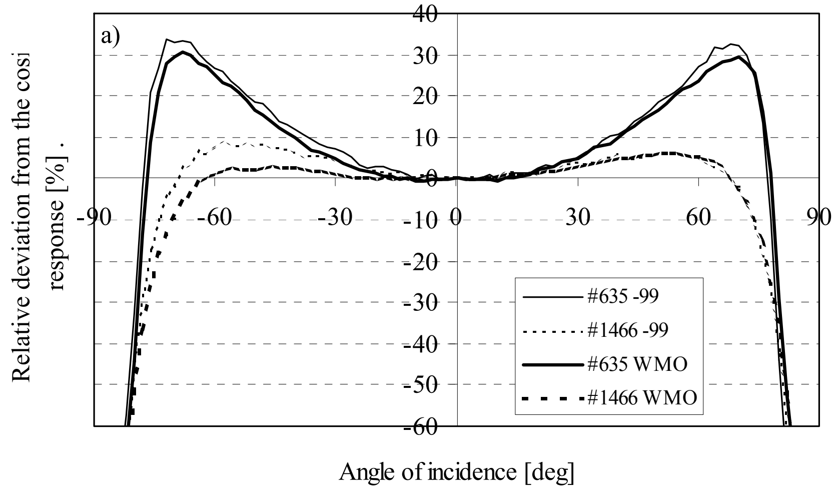
4. RESULTS

4.1 Dark room measurements

4.1.1 Cosine responses

Cosine responses of the two SL 501 meters, #635 and #1466, together with the deviation of the cosine responses from the ideal cosine function as measured in '95 and '99 are shown in Fig. 1 (a). Relative deviation between the measurements by STUK in '95 and '99 is presented in Fig. 1 (b). The comparison of results in '99 with the '95 data indicates stability of the angular responses within the measurement uncertainties.

(a)



(b)

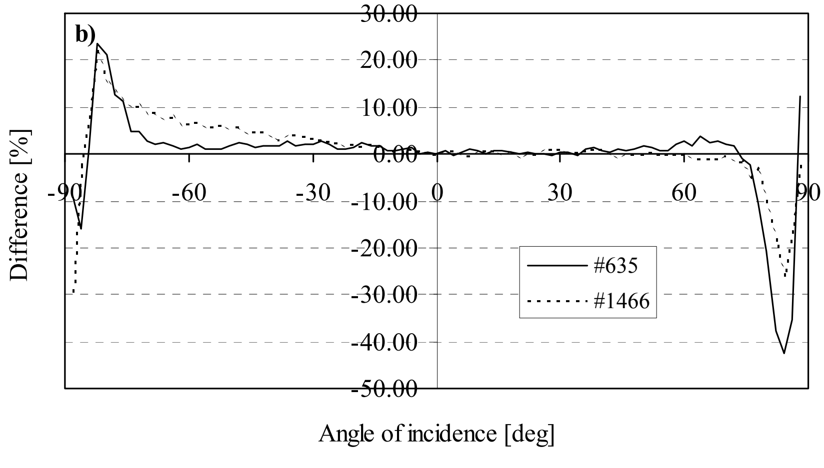
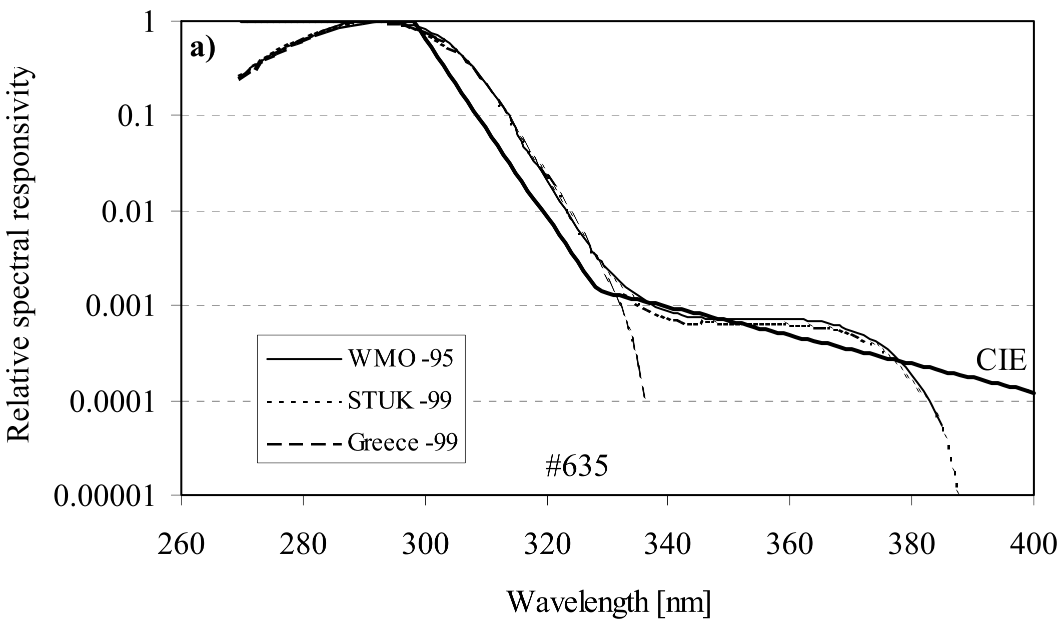


Figure 1. Deviation of the angular response from the ideal cosine response for the two SL 501 radiometers as measured at STUK during the WMO/STUK '95 intercomparison and in 1999 (a), percentage deviation between the measurements by STUK in 1995 and 1999 (b).

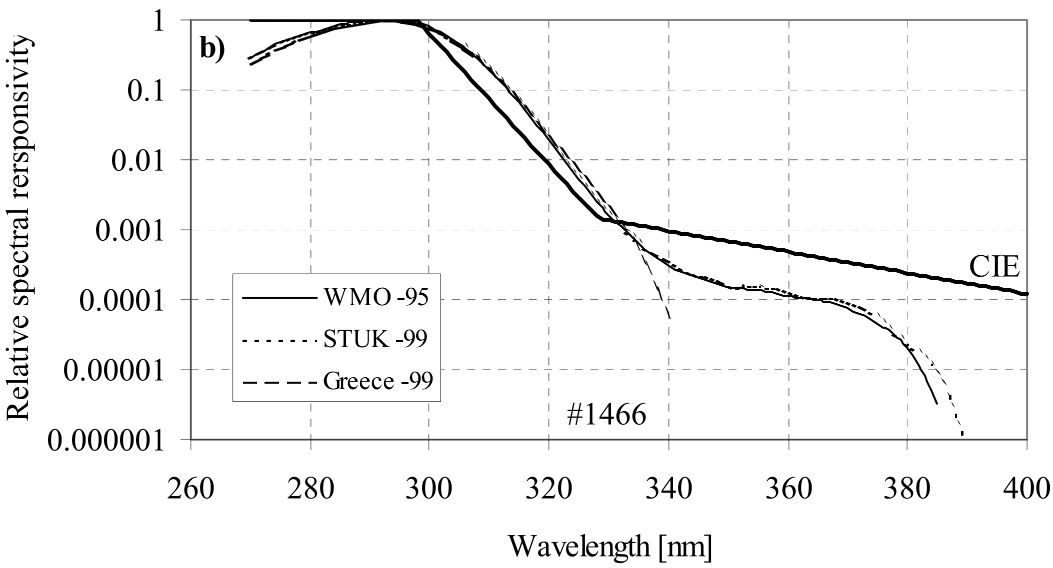
4.1.2 Spectral responsivities

Relative spectral responsivities of the SL 501 meters #635 and #1466 together with the manufacturer data and CIE weighting function are presented in Fig.2 (a) and (b). The deviations of the measurements by STUK and UTH in 1999 (Bais et al. 2000) from the WMO/STUK '95 intercomparison results are illustrated in Fig. 2 (c). The results by STUK in 1999 agree with the 1995 data within the measurement uncertainties. The results by UTH (Greece-99) agree with the WMO/STUK '95 intercomparison data in the UV-B range. Beyond 320 nm, the results by UTH indicate limited dynamic range of the spectral responsivity measurement. The comparison of the results by STUK in 1999 with the '95 data indicates stability of the spectral responsivities within the measurement uncertainties.

(a)



(b)



(c)

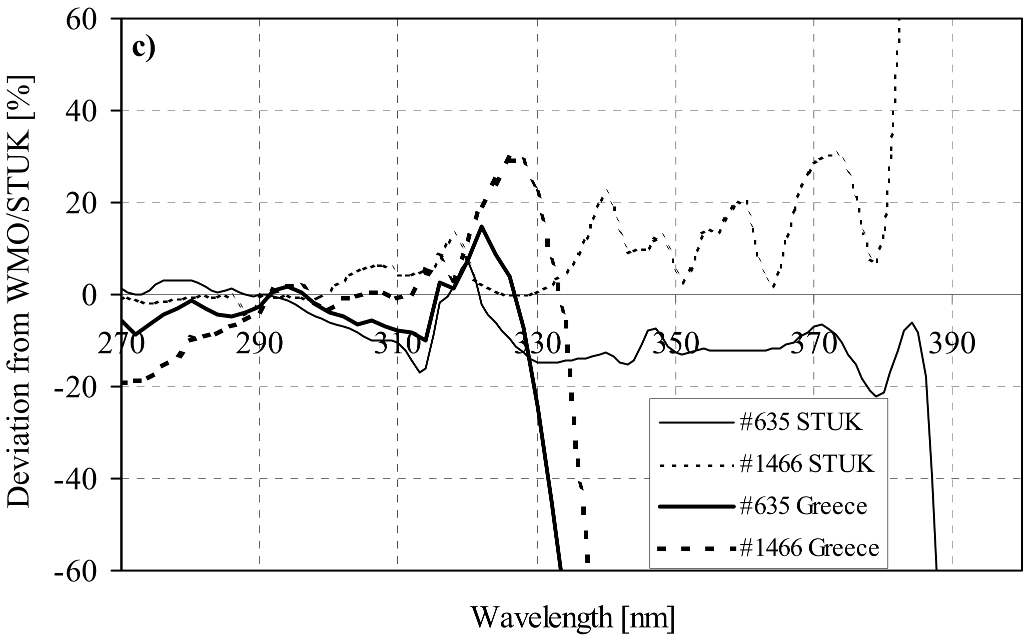


Figure 2. **Spectral responsivities of the SL 501 meters # 635 (a) and #1466 (b) as measured during WMO/STUK '95 intercomparison and in 1999 by STUK, and UTH (Bais et al. 2000). (c) Percentage deviations of the 1999 results from the WMO/STUK '95 intercomparison data.**

4.1.3 Halogen lamp measurements

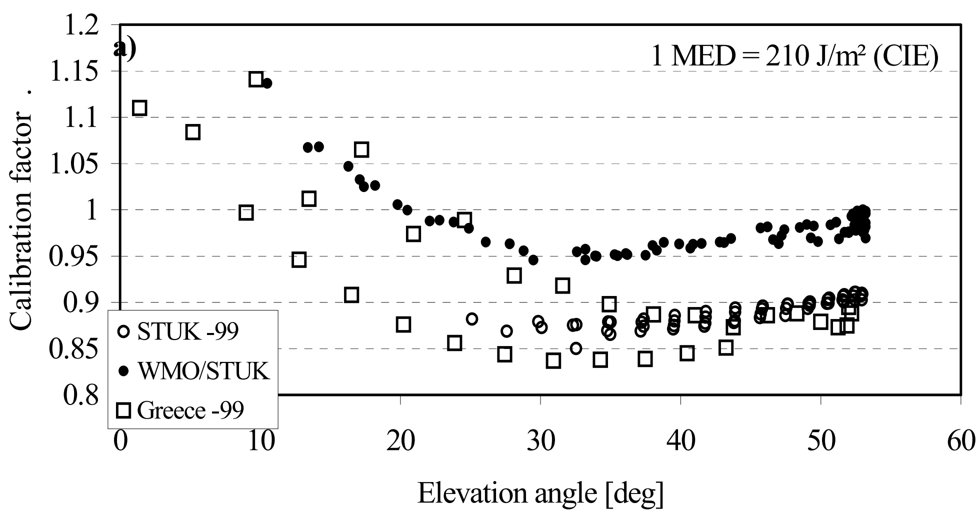
The results from the 1 kW halogen lamp measurements in 1999 when compared with the 1995 reference values were within 1.0 and 3.5%, for the # 635 and # 1466, respectively, indicating no change in the response of the meters.

4.2 Solar measurements

4.2.1 Calibration factors of the broadband meters

Calibration factors (CF's) of the SL 501 broadband radiometers #635 and #1466 obtained in 1995 and 1999 are presented as a function of elevation angle in Fig. 3.

(a)



(b)

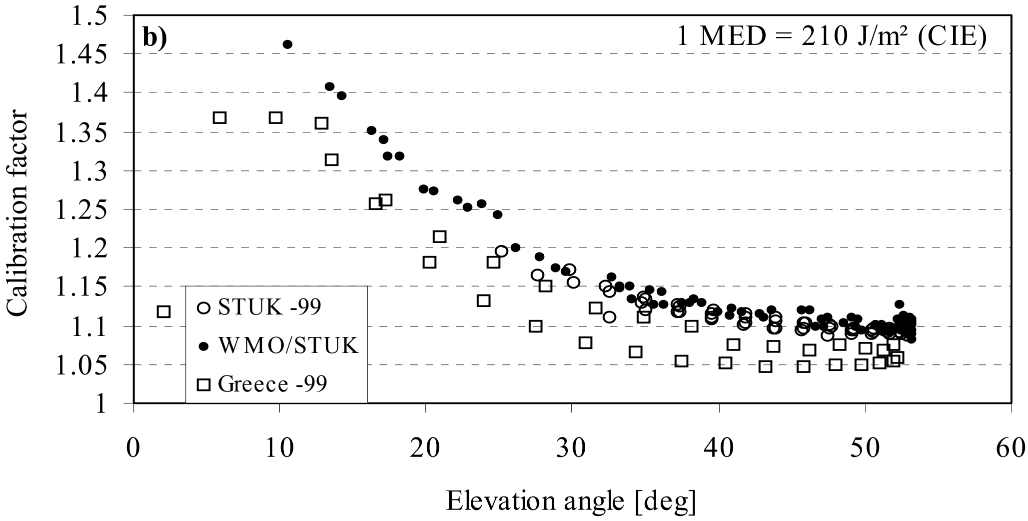


Figure 3. **Calibration factors (CF's) of the SL 501 # 635 (a) and # 1466 (b) as a function for solar elevation angle obtained at STUK in Finland in 1995 and in 1999, and in Greece in 1999 (Bais et al. 2000).**

The average values of the CF's at the solar elevations higher than 35^{o} are presented in Table 1. The measurement data have been numerically corrected for the non-ideal cosine response of the reference spectroradiometer (DM 150 of ATI in 1995 and DM 150 of STUK in 1999).

Table 1. **The average values of CF's of the SL 501 meters # 635 and # 1466 at the solar elevations higher than 35^{o}.**

Meter	Calibration factor		
	1995 / STUK	1999 / STUK	1999 / Greece [1)]
# 635	0,98	0,89	0,882
# 1466	1,11	1,10	1,065

[1)] *(Bais et al. 2000)*

The average values of the CF's as obtained by STUK in 1995 and 1999 agree within estimated calibration uncertainty. Also, the CF's obtained in Greece agree with the results by STUK in 1999. However, the results for the #635 meter indicate slightly increased sensitivity, whereas results for # 1466 indicate actual stability of this meter.

In case of #635 meter, there appears a relatively large deviation of the individual CF's obtained at approximately same solar elevations in Greece at solar elevations lower than ca. 45° (Bais et al. 2000).

5. CONCLUSIONS

Test results for two erythemally weighted broadband radiometers indicated stability of these meters over four years within measurement uncertainties. Calibration factors, cosine and spectral responsivities determined in '99 by STUK agreed with the results from the WMO/STUK intercomparison in '95. Also, results obtained in '99 by two laboratories, STUK and UTH, at different locations agreed within measurement uncertainties.

However, the calibration results for one of the meters, even though within measurement uncertainties, indicated change of the sensitivity of the meter by several percentages. Hence, to confirm the stability of broadband meters, frequent recalibration of the broadband meters is necessary on annual basis, preferably twice a year.

Acknowledgements

The authors thank Dr Bais and Dr Blumthaler for receiving the measurement data from the LAP/COST/WMO Intercomparison.

References

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