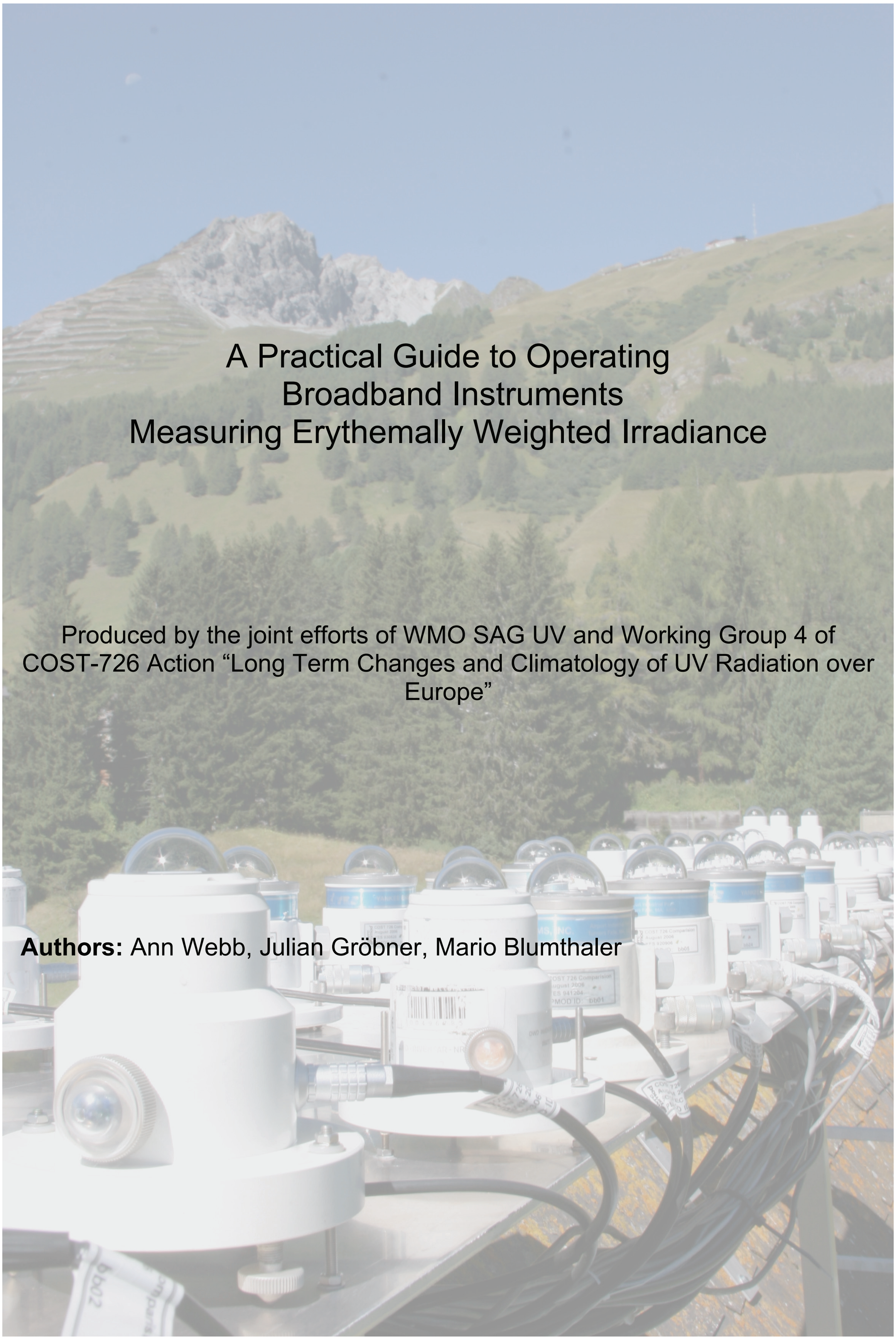

A Practical Guide to Operating Broadband Instruments Measuring Erythemally Weighted Irradiance

Produced by the joint efforts of WMO SAG UV and Working Group 4 of COST-726 Action “Long Term Changes and Climatology of UV Radiation over Europe”

Authors: Ann Webb, Julian Gröbner, Mario Blumthaler

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FOREWORD

This publication is a joint initiative between COST 726 (Long Term changes and Climatology of UV Radiation over Europe) and the World Meteorological Organisation (WMO) Global Atmospheric Watch (GAW).

Working Group 4 of COST 726, and the WMO Scientific Advisory Group for UV Measurements, were charged with developing Standard Operating Procedures (SOPs) for broadband UV instruments. The combined expertise of both groups has produced this document which is applicable both within GAW and within the wider UV community.

A major goal of working group 4 of COST 726 is the homogenization of erythemally weighted UV Radiation measurements by regional and national networks in Europe. Thus, efforts were undertaken to produce common Quality Assurance/Quality Control guidelines to be used by network operators for operating UV radiometers. Vital elements in GAW station operations are the Standard Operating Procedures (SOPs) for different instruments. These ensure uniform good practice throughout the network, and thus improve data quality. The clear accord between GAW and COST 726 on this issue has resulted in the Guide to Operation presented here and endorsed by both organizations.

The GAW SOPs provide guidelines on instrument operation and maintenance, and also details of calibration procedures and data protocols to follow within the GAW system. While the latter may be specific to the GAW network, best practice in instrument operation is a common goal for both GAW sites and all other network or independent sites globally.

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Scope & Applicability

Solar UV radiation incident at the Earth's surface depends upon atmospheric transmission while its short wavelength limit is determined by ozone absorption, primarily in the stratosphere. The energy of UV photons causes many biological and chemical effects e.g. sunburn, vitamin D synthesis, photolysis of ozone and NO_2. Monitoring UV is therefore important both as an indicator of the state of the atmosphere, and a determinant of numerous biological and chemical effects.

Instruments to monitor solar UV radiation fall into three main categories. Within each there are a variety of different instrument makes and designs. Measurements may be classed as spectral (providing spectral detail at a resolution of less than 1nm), multiband (several channels of narrow bandwidth e.g. 2 – 10 nm wide), and broadband (a single measure of all or part of the UV waveband). All three categories of instrument are in operation at GAW stations. Regional and collaborative networks also contribute to the global coverage of UV measurements, although there are still gaps in this coverage.

Even within each category of UV instrument there is no single standard instrument. However, the principles of operation apply to all instruments no matter who the manufacturer. This guide is intended for station operations, it does not cover the details of instrument calibration and characterisation.

Therefore, this Guide should be read in conjunction with the GAW publications 125,126, 146, and 164 which provide greater detail and background information than are necessary for an operational document:

- 125 Instruments to measure solar ultraviolet radiation Part 1: Spectral instruments (referred to as the Spectral document) (1)
- 126 Guidelines for site quality control of UV monitoring (referred to as the QC document) (2)
- 146 Quality Assurance in monitoring solar ultraviolet radiation: the state of the art. (3)
- 164 Instruments to measure solar ultraviolet radiation Part 2: Broadband instruments measuring erythemally weighted solar irradiance (referred to as the Broadband document) (4) – in press, draft available on the web http://www.wmo.ch/web/arep/reports/gaw164_final_draft.pdf

Summary of Method

An instrument to measure broadband UV radiation is taken, for the purposes of GAW, to be a device that approximately measures the erythemally effective UV radiation incident on a horizontal surface. The device produces an electrical signal that is recorded and logged, and is converted into units of erythemally effective irradiance through the process of calibration.

The instrument should be characterised for its spectral response and angular response, and its sensitivity to temperature (and if possible humidity). These characteristics should be checked at regular intervals to determine their stability. The spectral response is incorporated into the calibration; as to a certain extent is the angular response. The temperature of the instrument should be maintained for accurate measurements, but the temperature within the instrument should be monitored and the signal corrected if there is significant change. Changes in sensitivity due to humidity are much harder to identify and should be minimised as much as possible by maintaining a constant dry environment within the instrument.

Once the instrument is correctly installed its operation consists of a series of daily, weekly and annual (or 6-month) checks. Therefore, the instrument site must be easily and safely accessible.

Data Acquisition, Calculations & Data Reduction

The electrical signal (U) produced by the broadband UV instrument is usually in analogue form and is related to the incoming erythemally weighted irradiance. This should be converted into digital format for electronic logging. A sampling frequency of between once per second (1Hz) and once per minute may be used (the shorter period is recommended), and the data stored as averages, preferably over time periods of not more than 10 minutes, if the complete data set is not kept. Whenever possible the variation about the mean should also be recorded for each averaging period. This indicates the constancy of the conditions during the averaging period (e.g. rapidly changing cloud or clear sky / constant cloud).

The raw signal must be converted into units of erythemal irradiance (Wm^{-2}) by application of the calibration factor. This requires knowledge of the time (SZA) and ozone amount at the time of measurement.

$$E_{CIE} = (U - U_{offset}) \cdot C \cdot f_n\,(SZA, TO_3) \cdot \varepsilon(T) \cdot Coscor \qquad (1)$$

Where:

- E_{CIE} is erythemal effective irradiance,
- U is the measured electrical signal from the radiometer,
- U_{offset} is the electrical offset for dark conditions,
- C is the calibration coefficient, a constant value determined for specific conditions i.e. SZA of 40º and total ozone column of 300 DU.
- f_n (SZA, TO_3) is a function of solar zenith angle (SZA) and total column ozone (TO_3) i.e. the function can be expressed as a calibration matrix (or look up table) and is derived as part of the calibration procedure. It is normalised at a SZA of 40º and total ozone column of 300 DU. For solar zenith angles less than 40^0 f_n (SZA, TO_3) is often nearly unity.
- $\varepsilon(T)$ is the temperature correction function (It is recommended that the instrument is temperature stabilised. If this fails then a correction should be applied, which is complex and not always successful).
- Coscor is the cosine correction function (if necessary, otherwise =1)

U_{offset} is the signal recorded in darkness. Identify this value as the signal logged during the hours of darkness (or by covering the input optics if there is no period of darkness) and record the daily offset (mean and standard deviation over the period when the sun is more than 10º below the horizon). If there are systematic changes in offset during the night / year this may indicate a temperature sensitivity. An increase in the random variability may indicate problems with e.g. electrical stability.

The units for the measured erythemally effective irradiance should be stated as (Wm^{-2} effective), not to be confused with the purely physical measurement of radiation in Wm^{-2} (unweighted by a biological weighting function).

An alternative way of specifying the erythemally effective irradiance is in terms of the dimensionless UV Index (UVI). The UVI is a measure of the intensity of solar UV radiation at the Earth's surface that is used for public information. The index is expressed by multiplying the erythemally weighted irradiance in Wm^{-2} by 40.0 $W^{-1}m^2$ (this will lead to an open-ended index which is normally between 0 and 16 at sea level, but with larger values possible at high altitudes). [ICNIRP, 1995]

Health & Safety Warnings (indicating operations that could result in personal injury or loss of life and explaining what will happen if the procedure is not followed or is followed incorrectly)

- Electrical supply – care with mains supply.
- Do not use blue silica gel, toxic
- Instruments installed at height e.g. rooftop must be well secured, and suitable safety precautions taken with access.

Cautions (indicating activities that could result in equipment damage, degradation of sample or possible invalidation of results)

- Instrument must be well secured.
- Caution when cleaning dome, use lint free wipes, and follow manufacturer's advice regarding suitable solvents.
- Power and data cables to be routed to avoid trip hazard, suitably secured and protected from harsh environment where necessary e.g. enclosed within a PVC tube.
- In locations where power supplies are subject to frequent interruption a back up power supply of battery or UPS should be available, with automatic switching in the event of a power failure.

Interferences

- Deviation from flat horizon, minimise by avoiding local obstructions (e.g. trees, poles, buildings). If unavoidable, place obstruction to north (or south in southern hemisphere).
- Avoid reflections from local objects (e.g. windows, metal roofs)
- Cable length – ensure no interference (e.g. electrical cross talk from other installations) or significant loss of signal along cable length.
- Temperature (stabilise and monitor where necessary)
- Humidity (keep constant – dry – within instrument body)
- Note any local bright light sources e.g. security lights, floodlights as these can influence dark readings.
- Prevent shading of instrument by personnel.
- Prevent shading, reflections and light sources, from other instruments on the site.

Installation

The installation site should be carefully selected to ensure that the instrument is not in shadow at any time of the day or year, and views as flat a horizon as the site allows i.e. the elevations above a flat horizon as viewed by the instrument are minimised. Ideally the instrument should be mounted at a height of about 1.5 m, to allow cleaning and observation of the dome but minimise local disturbances. The instrument platform must be stable and the instrument securely fixed to the platform. The use of wood as a platform should be avoided as it can warp and disturb the instrument levelling. It is preferable to have the instrument unshaded and unobscured (objects subtending an angle of less than 5º degrees above horizon) which may require, for example, a rooftop location. Alternatively a purpose built tower may be used to mount the instrument, ensuring that it is stable and easy access to the instrument is provided. Note details of position and horizon in station log.

Follow the instrument manufacturer's recommendations for installation, bearing in mind the points in the sections above. In addition the following are recommended:

- **Verification of the spectral and angular response.**

  Typical or actual spectral and angular responses may be provided by the manufacturer, but should be verified especially if the characteristics provided are only "typical of the instrument type" and not specific to the particular instrument deployed. Details of these procedures may be found in GAW publication 164, or they can be performed by an independent laboratory, often as part of a calibration.

- **Check that the instrument is optically levelled.**

  A simple spirit level in the body of the instrument indicates if the instrument body is level. In using this, the physical body and receiving optics are assumed to share the same horizontal plane. If this is not the case then levelling the instrument with respect to the body will not level the receiving optics, resulting in an apparent azimuthal response. The alignment of the two horizontal planes can be checked by levelling the radiometer body and then rotating it carefully, recording the signal every 10º of azimuth when the radiometer body is level. This should be done at a time of constant solar irradiance i.e. at noon on a cloudless day. Any significant and systematic variation in the measured signal as the radiometer is rotated indicates a misalignment of the horizontal planes (or some other azimuth effect)

Computer Hardware & Software

- **Data acquisition system.**

  No specification necessary – any suitable data logger or computer may be used. However, it is necessary to ensure that the time stamp on the measurements is correct, i.e. the data logger has the correct time. This may be done by using signals from a radio clock (often difficult to receive), or a GPS system directly through a GPS or via the internet. It is possible to install an automatic system to check computer time, or this should be done manually at the frequency required by the performance of the logger / computer. The time should not be allowed to differ by more than 10 seconds from GPS time.

- **Data averaging.**

  The time stamp of the measurements that are an average over a time period should be clearly stated and should be consistent with any requirements from network or database requirements with which the instrument is associated. When only measurement averages are stored, information on the measurement variability during the averaging period should be stored in addition (i.e. standard deviation, minimum and maximum value).

Instrument Maintenance (consistent with GAW publication 164)

Note the time and actions taken in the appropriate checklist and logbook, for all interventions.

1. Daily:

- **Check the input optics and clean if necessary.**

  This first task should be performed as early as possible in the morning.

  The input optics (quartz dome) should be free of dust, dirt, marks and smears, and also cleaned of frost, ice, snow and water droplets. The input optics can be cleaned by wiping with a lint-free cloth soaked in an appropriate solvent (one that does not leave a residue). Avoid excessive heat and force in removing ice.

  If the dome is cracked or chipped it must be replaced and then the instrument recalibrated.

- **Check for condensation in the dome.** To remove moisture the desiccant may need to be changed several times. In addition the instrument may need cleaning, repair, replacement and recalibration.
- **Check the operation of the data acquisition system**, including correct time and date.

2. Weekly:

- **Check the humidity indicator and exchange if necessary.**

  The air in the body of the detector is kept dry by a desiccant cell. Frequency of replacement will depend on the operating environment for the instrument. Note: In some environments the drying capacity provided may not be sufficient.

- **Check temperature stabilization is operating if available**

  Some broadband UV radiometers are temperature stabilized while others are deemed to be sufficiently insensitive to temperature not to require active stabilization. If the internal temperature of the meter is recorded check that this is stable.

- **Check levelling**

  A circular spirit level in the body of the instrument indicates whether or not it is level. If the indicator bubble has moved off center the instrument must be adjusted until the bubble is centralized.

- **Determination of offset**

  Most instruments provide an automated offset-determination during the dark hours, although this should be done manually in Polar Regions.

- **Check auxiliary power supply**

  If a back up power supply is in use check that the system is fully charged.

- **Connectors and cabling**

  In some environments corrosion can be a problem. Visually inspect the connectors for corrosion and replace cable if necessary. In dry environments this check may be made less frequently.

3. **At least once per year** (every six months if possible):

- **Check instrument stability by comparison to a reference broad-band instrument (one with a carefully maintained calibration), or spectroradiometer**. Measurement networks, including GAW, can advise on suitable reference instruments and/or laboratories providing this service. The calibration may be performed on site or at a calibration laboratory. If these options are not available, comparison against a suitable calibrated lamp may be helpful. Details of these procedures may be found in GAW publication 164.

If the site instrument has changed then there are several possibilities:

1. If the change from the reference instrument is a function of SZA, which we define by a change that differs by more than 3% for SZA between 75º and the daily minimum (noon) SZA, then the site instrument requires a full recalibration (the SZA dependency implies e.g. a change in the spectral response)
2. If the reference instrument is reliable and the change from the reference instrument is constant with SZA (the variation is less than 3% over the range of SZA above) then the calibration coefficient (C in equation 1) may simply be adjusted and there is no need to undertake a full recalibration and recalculation of the calibration matrix.

3. If moisture has entered the instrument the calibration can change. The instrument may return to normal after exchanging the desiccant pack a sufficient number of times to dry it, but in some cases recalibration may be necessary.

- **Check the operation and calibration of electronic supporting devices** (data loggers, A/D boards, signal amplifiers, cables, etc.)
- **Check the dark signal stability during the year**. Instability may suggest temperature dependence of the electronics or other problems. The offset during darkness is recorded during daily or weekly checks.

Data Management & Records Management

- **Back up data daily at local site.**
- **Record Management**

  As important as the data are the metadata records detailing the instrument history and operation. These should include the instrument identification and characteristics, the exact location of the instrument and a history of any changes. Every new calibration, characterisation and change of any element of the instrument system, including cabling and logger, should be recorded. For example, a table with calibration dates and information provides a quick check of currency of calibration. Log books, record sheets and check sheets used at the station should be archived and form part of this metadata.

Example checklist

Station Name XXXXX

Period covered by checklist 02 – 06 January, 2005

Daily Entries

Year	2005						
Date	02-Jan	03-Jan	04-Jan	05-Jan	06-Jan	07-Jan	08-Jan
Day of year	002	003	004	005	006	007	008
Operator	GD	CC	GD	GD	GD	GD	GD
Time(UT)	12:15	12:35	13:35	12:35	13:25	17:13	18:50
Time Shift(1) (sec)	+9	+10	0	-1	-2	-3	-4
Time Corrected(2)	No	+1	No	No	No	No	No

(1), (2) If GPS or other time control/correction device is not provided with the system.
(2) Only when required

Collector conditions before cleaning

(c=clear, s=snow, w=water, f=frost, l=light, h=heavy, r=raining, d=dust)

Date	02-Jan	03-Jan	04-Jan	05-Jan	06-Jan	07-Jan	08-Jan
Instrument type	c	C	w	c	r	c	c

Error messages:

Jan 03 5:58:23 AM, 1, GPS communication error

Special Events

Jan 06 from 12:00 to 12:30 GMT, Personnel working on the roof.

Weekly Entries

Date: 3 Jan 2005 (Day of Year 003)

Operator: CC

Level Check	OK
Determine / Check dark current[(3)]	Check OK
Check humidity indicator[(4)]	Drying agent changed
Check temperature stabilisation[(5)]	OK
Weekly graph of noon values[(6)]	OK
Storage Drive Volume remaining	1352 Mb

[(3)] Determine if necessary (polar regions), or check values for previous week to ensure within normal range
[(4)] Note if drying agent changed
[(5)] Where applicable
[(6)] Comparison with previous years, same Day of year, or with modelled values

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