

CHAPTER 8 — MEASUREMENT OF SUNSHINE DURATION

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MEASUREMENT OF SUNSHINE DURATION

8.1 General

The term sunshine is associated with the brightness of the solar disk exceeding the background of diffuse sky light, or — better observable by the human eyes — with the appearance of shadows behind illuminated objects. As such, the term is related more to visual radiation than to energy radiated at other wavelengths, although both aspects are inseparable. In practice, however, the first definition was established directly by the relatively simple Campbell-Stokes sunshine recorder (section 8.2.1), which detects sunshine if the beam solar energy concentrated by a special lens is able to burn a special dark paper card. This recorder was already introduced in meteorological stations in 1880 and is still used in many networks. Since no international regulations about the dimensions and quality of the special parts were fixed, accomplishing different laws of the principle gave different sunshine duration values.

In order to homogenize the data of the worldwide network for sunshine duration, a special design of the Campbell-Stokes sunshine recorder, the so-called Interim Reference Sunshine Recorder (IRSR), was recommended as reference by WMO in 1962 (WMO, 1962). The improvement by this “hardware definition” was effective only during the interim period needed for finding a precise physical definition allowing for both designing automatic sunshine recorders and approximating the “scale” represented by the IRSR as near as possible. With regard to the latter, the settlement of a direct solar threshold irradiance corresponding to the burning threshold of the Campbell-Stokes recorders was strongly suggested. Investigations at different stations showed that the threshold irradiance for burning the card varies between 70 and 280 W m⁻² (Bider, 1958; Baumgartner, 1979). But further investigations, especially performed with the IRSR in France, resulted in a mean value of 120 W m⁻², which was finally proposed as the threshold of direct solar irradiance to distinguish bright sunshine*. With regard to the spread of test results, a threshold accuracy of 20 per cent in instrument specifications is accepted. A pyrheliometer was recommended as reference sensor for the detection of the threshold irradiance. For future refinement of the reference, the settlement of the field-of-view angle of the pyrheliometer seems to be necessary (WMO, in preparation).

8.1.1 Definition

According to Recommendation 10 (CIMO-VIII) sunshine duration during a given period is defined as the sum of that subperiod for which the direct solar irradiance exceeds 120 W m⁻².

* Recommended by the Commission for Instruments and Methods of Observation at its eighth session, 1991, through Recommendation 10 (CIMO-VIII).

8.1.2 Units and scales

The physical quantity of sunshine duration (*SD*) is, evidently, time. The units used are seconds or hours. For climatological purposes, derived terms such as “hours per day” or “daily sunshine hours” are used, as well as percentage quantities, such as “relative daily sunshine duration”, where *SD* may be related to the extra-terrestrial possible or to the maximum possible sunshine duration (*SD₀* and *SD_{max}*, respectively). The measurement period (day, decade, month, year, etc.) is an important addendum to the unit.

8.1.3 Meteorological requirements

Performance requirements are given in Chapter 1, Part I. Hours of sunshine should be measured with an uncertainty of ±0.1 hours and a resolution of 0.1 hours.

Since the number and the steepness of the threshold transitions of direct solar radiation determine the possible uncertainty of sunshine duration, the meteorological requirements on sunshine recorders are essentially correlated with the climatological cloudiness conditions (WMO, 1985).

In the case of cloudless sky, only the hourly values at sunrise or sunset constellations can (depending on the amount of dust) be erroneous because of an imperfectly adjusted threshold or spectral dependencies.

In the case of scattered clouds (Cumulus, Stratocumulus) the steepness of the transition is high and the irradiance measured from the cloudy sky with a pyrheliometer is generally lower than 80 W m⁻²; that means low requirements on the threshold adjustment. But the field-of-view angle of the recorder can influence the result if bright cloud clusters are near the Sun.

The highest precision is required if high cloud layers (Cirrus, Altostratus) with small variations of the optical thickness attenuate the direct solar irradiance around the level of about 120 W m⁻². The field-of-view angle is effective as well as the precision of the threshold adjustment.

The requirements on sunshine recorders vary, depending on site and season, according to the dominant cloud formation. The latter can be roughly described by three ranges of relative daily sunshine duration *SD/SD₀* (see section 8.1.2), namely “cloudy sky” by ($0 \leq SD/SD_0 < 0.3$), “scattered clouds” by ($0.3 \leq SD/SD_0 < 0.7$) and “fair weather” by ($0.7 \leq SD/SD_0 \leq 1.0$). The results for dominant clouded sky generally show the highest percentage of deviations from the reference.

8.1.3.1 APPLICATION OF SUNSHINE DURATION DATA

One of the first applications of *SD* data was to characterize the climate of sites, especially of health resorts. This considers also the psychological effect of strong solar light on human well-being.

The description of past weather conditions, for instance of a month, usually contains the course of daily *SD* data. If solar energy data are not available, such *SD* values are valuable for agricultural purposes (WMO, 1981).

For these fields of application, an uncertainty of about 10 per cent of mean *SD* values seemed to be acceptable over many decades.

8.1.3.2 CORRELATIONS TO OTHER METEOROLOGICAL VARIABLES

The most important correlation between sunshine duration and global solar radiation *G* is described by the so-called Ångström formula:

$$G/G_0 = a + b \cdot (SD/SD_0)$$

where G/G_0 is the so-called clearness index (related to the extra-terrestrial global irradiation), SD/SD_0 is the corresponding sunshine duration (related to the extra-terrestrial possible *SD* value), and *a* and *b* are constants which have to be determined monthly. The uncertainty of the monthly means of daily global irradiation derived in this way from Campbell-Stokes data was found to be lower than 10 per cent in summer, and rose up to 30 per cent in winter, as reported for German stations (Golchert, 1981).

The Ångström formula implies the inverse correlation between cloud amount and sunshine duration. This relationship is not fulfilled for high and thin cloudiness and obviously not for cloud fields which do not cover the Sun, so that the degree of inverse correlation depends first of all on the magnitude of the statistical data collected (Stanghellini, 1981; Angell, 1990). The improvement of the accuracy of *SD* data should reduce the scattering of the statistical results, but even perfect data can generate sufficient results only on a statistical basis.

8.1.3.3 REQUIREMENT OF AUTOMATED RECORDS

Since electrical power is available in an increasing number of places, the advantage of the Campbell-Stokes recorder of being self-sufficient is of decreasing importance. Furthermore, the required daily maintenance regarding the replacement of the burn card makes the use of Campbell-Stokes recorders problematic at either automatic weather stations or stations with reduced personnel. Another essential reason to replace Campbell-Stokes recorders by new automated measurement procedures is to avoid the expense of visual evaluations and to obtain more precise results on data carriers permitting direct computerized data processing.

8.1.4 Methods of measurement

The principles used for measuring sunshine duration and the pertinent types of instruments are briefly listed in the following methods:

- (a) Burn method. Threshold effect of paper burning caused by focused direct solar radiation (heat effect of absorbed solar energy). Duration readable from burn.

Type of instrument: Campbell-Stokes sunshine recorders, especially the recommended version IRSR (see sections 8.1 and 8.2);

- (b) Pyrheliometric method. Pyrheliometric detection of the transition of the direct solar irradiance through the 120 W m⁻² threshold (according to Recommendation 10 (CIMO-VIII)). Duration values readable from time counters triggered by the appropriate upward and downward transitions.

Type of instrument: pyrheliometer combined with an electronic or computerized threshold discriminator and a time-counting device;

- (c) Pyranometric method. Pyranometric measurement of global (*G*) and diffuse (*D*) solar irradiance to derive the direct solar irradiance as the WMO threshold discriminator value and further as in (b) above.

Type of instrument: all radiometer systems of two fitted pyranometers and one sunshade device combined with an electronic or computerized threshold discriminator and a time-counting device;

- (d) Contrast method. Discrimination of the insolation contrasts between some sensors in different positions to the Sun with the aid of a special difference of the sensor output signals which corresponds to an equivalent of the WMO recommended threshold (determined by comparisons with reference *SD* values and further as in (b) above.

Type of instrument: specially designed multisensor detectors (mostly equipped with photovoltaic cells) combined with an electronic discriminator and a time counter;

- (e) Scanning method. Discrimination of the irradiance received from continuously-scanned, small sky sectors with regard to an equivalent of the WMO recommended irradiance threshold (determined by comparisons with reference *SD* values).

Type of instrument: one-sensor receivers equipped with a special scanning device (rotating diaphragm or mirror, for instance) and combined with an electronic discriminator and a time-counting device.

The sunshine duration measurement methods described in the following paragraphs are examples of ways to achieve the above-mentioned principles. Instruments using these methods, with the exception of the Foster switch recorder, participated in the WMO Automatic Sunshine Duration Measurement Comparison in Hamburg from 1988 to 1989 and in the comparison of pyranometers and electronic sunshine duration recorders of Regional Association VI in Budapest in 1984 (WMO, 1986).

The description of the Campbell-Stokes sunshine recorder in section 8.2.1 is relatively detailed since this instrument is still widely used in national networks and the specifications and evaluation rules recommended by WMO should be considered.

A historical review of sunshine recorders is given in Coulsen (1970), Hameed and Pittalwala (1989), and Sonntag and Behrens (1992).

8.2 Instruments and sensors

8.2.1 The Campbell-Stokes sunshine recorder (burn method)

The Campbell-Stokes sunshine recorder consists essentially of a glass sphere mounted concentrically in a section of a spherical bowl, the diameter of which is such that the Sun's rays are focused sharply on a card held in grooves in the bowl. The method of supporting the sphere differs according to whether the instrument is operated in polar, temperate, or tropical latitudes. To obtain useful results, both the spherical segment and the sphere should be made with great precision, the mounting being so designed that the sphere can be accurately centred in it. Three overlapping pairs of grooves are provided in the spherical segment to permit the cards to be suitable for different seasons of the year (one pair for both equinoxes), their length and shape being selected to suit the geometrical optics of the system. It should be noted that the aforementioned problem of the burns obtained under variable cloud conditions indicates that this instrument, and indeed any instrument using this method, does not provide accurate data of sunshine duration.

The table below summarizes the main specifications and requirements for a Campbell-Stokes sunshine recorder of the IRSR grade. A recorder to be used as an IRSR should comply with the detailed specifications issued by the British Meteorological Office and IRSR record cards should comply with the detailed specifications issued by *Météo France*.

8.2.1.1 ADJUSTMENTS

In installing the recorder, the following adjustments are necessary:

- (a) The base must be levelled;
- (b) The spherical segment should be adjusted so that the centre line of the equinoctial card lies in the

celestial Equator (the scale of latitude marked on the bowl support facilitates this task);

- (c) The vertical plan through the centre of the sphere and the noon mark on the spherical segment must be in the plane of the geographic meridian (north-south adjustment).

A recorder is best tested for (c) above by observing the image of the Sun at the local apparent noon; if the instrument is correctly adjusted, then the image should fall on the noon mark of the spherical segment or card.

8.2.1.2 EVALUATION

In order to obtain uniform results from Campbell-Stokes recorders, it is especially important to conform closely to the following directions for measuring the records of IRSR. The daily total duration of bright sunshine should be determined by marking off on the edge of a card of the same curvature the lengths corresponding to each mark and by measuring the total length obtained along the card at the level of the recording to the nearest tenth of an hour. The evaluation of the record should be made as follows:

- (a) In the case of a clear burn with round ends, the length should be reduced at each end by an amount equal to half the radius of curvature of the end of the burn; this will normally correspond to a reduction of the overall length of each burn by 0.1 hour;
- (b) In the case of circular burns, the length measured should be equal to half the diameter of the burn. If more than one circular burn occurs on the daily record it is sufficient to consider two or three burns as equivalent to 0.1 hour of sunshine; four, five, six burns as equivalent to 0.2 hour of sunshine; and so on in steps of 0.1 hour;
- (c) Where the mark is only a narrow line, the whole length of this mark should be measured, even when the card is only slightly discoloured;

Campbell-Stokes recorder (IRSR grade) specifications

| Glass sphere | | Spherical segment | | Record cards | |
|-------------------|----------------------------|----------------------------|--|------------------|---|
| Shape: | Uniform | Material: | Gunmetal or equivalent durability | Material: | Good quality pasteboard not affected appreciably by moisture |
| Diameter: | 10 cm | Radius: | 73 mm | Width: | Accurate to within 0.3 mm |
| Colour: | Very pale or colourless | Additional specifications: | (a) Central noon line engraved transversely across inner surface; | Thickness: | 0.4 ± 0.05 mm |
| Refractive index: | 1.52 ± 0.02 | | (b) Adjustment for inclination of segment to horizontal according to latitude; | Moisture effect: | Within 2 per cent |
| Focal length: | 75 mm for sodium "D" light | | (c) Double base with provision for leveling and azimuth setting. | Colour: | Dark, homogeneous, no difference detected in diffuse daylight |
| | | | | Graduations: | Hour-lines printed in black |

- (d) Where a clear burn is temporarily reduced in width by at least a third, an amount of 0.1 hour should be subtracted from the total length for each such reduction in width, but the maximum subtracted should not exceed one half of the total length of the burn.

In order to assess the random and systematic errors made while evaluating the records and to ensure the objectivity of the results of the comparison, it is recommended that the evaluations corresponding to each one of the instruments compared be made successively and independently by two or more persons trained in this type of work.

8.2.1.3 SPECIAL VERSIONS

Since the standard Campbell-Stokes sunshine recorder does not record all the sunshine received during the summer months at stations with latitudes higher than about 65°, some countries use modified versions.

One possibility is to use two Campbell-Stokes recorders operated back to back, one of them being installed in the standard manner while the other should be installed facing north.

In many climates, it may be necessary to heat the device to prevent deposition of frost and dew. Comparisons in climates like that of northern Europe between heated and normally operated instruments have shown that the amount of sunshine not measured by a normal version, but recorded by a heat device, is about 1 per cent of the monthly mean in summer and about 5 to 10 per cent of the monthly mean in winter.

8.2.1.4 SOURCES OF ERROR

The errors of this recorder are mainly generated by the dependence on the temperature and humidity of the burn card as well as by the overburning effect, especially in the case of scattered clouds (Ikeda, Aoshima and Miyake, 1986).

The morning values are frequently disturbed by dew or frost in middle and high latitudes.

8.2.2 *Pyrheliometric method*

8.2.2.1 GENERAL

This method, which represents a direct consequence of the WMO definition of sunshine (see section 8.1.1) and is, therefore, recommended to obtain reference values of sunshine duration, requires a weatherproof pyrheliometer and a reliable solar tracker to point the radiometer automatically or at least semi-automatically to the position of the Sun. The method can be modified by the choice of the pyrheliometer whose field-of-view angle influences the irradiance measured when clouds surround the Sun.

The sunshine threshold can be monitored by the continuous comparison of the pyrheliometer output with the threshold equivalent voltage $V_{th} = 120 \text{ W m}^{-2} \cdot R \mu\text{V W}^{-1} \text{ m}^2$, which is calculable from the responsivity

R of the pyrheliometer. A threshold transition is detected if $\Delta V = V - V_{th}$ changes its sign. The connected time counter is running when $\Delta V > 0$.

8.2.2.2 SOURCES OF ERROR

The field-of-view angle is not yet settled by agreed definitions. Higher differences between the results of two pyrheliometers with different field-of-view angles are possible, especially if the Sun is surrounded by clouds. Furthermore, typical errors of pyrheliometers, namely tilt effect, temperature dependence, non-linearity, and zero-offset, depend on the class of the pyrheliometer. Larger errors appear if the alignment to the Sun is not precise or if the entrance window is covered by rain or snow.

8.2.3 *Pyranometric method*

8.2.3.1 GENERAL

The pyranometric method to derive sunshine duration data is based on the fundamental relationship between the direct solar radiation (I) and the global (G) and diffuse (D) solar radiation:

$$I \cdot \cos \zeta = G - D \quad (8.1)$$

where ζ is the solar zenith angle and $I \cdot \cos \zeta$ is the horizontal component of I . To fulfil equation 8.1 exactly the shaded field-of-view angle of the pyranometer for measuring D has to be equal to the field-of-view angle of the pyrheliometer (see Chapter 7, Part I). Furthermore, the spectral ranges, as well as the time constants of the pyrheliometers and pyranometers, should be as similar as possible.

In the absence of a Sun-tracking pyrheliometer, but where computer-assisted pyranometric measurements of G and D are available, the WMO sunshine criterion can be expressed according to equation 8.1 by:

$$(G-D)/\cos \zeta > 120 \text{ W m}^{-2} \quad (8.2)$$

which is applicable to instantaneous readings.

The modifications of this method in different stations concern first of all:

- The choice of pyranometer;
- The shading device applied (shade ring or shade disk with solar tracker) and its shade geometry (shade angle);
- The correction of shade ring losses.

As a special modification, the replacement of the criterion in equation 8.2 by a statistically-derived parameterization formula (to avoid the determination of the solar zenith angle) for applications in more simple data acquisition systems should be mentioned (Sonntag and Behrens, 1992).

8.2.3.2 SOURCES OF ERROR

According to equation 8.2, the measuring errors in global and diffuse solar irradiance are propagated by the calculation of direct solar irradiance and are strongly amplified with increasing solar zenith angles. Therefore,

the accuracy of corrections for losses of diffuse solar energy by the use of shade rings (WMO, 1984) and the choice of pyranometer quality is of importance to reduce the uncertainty level of the results.

8.2.4 Contrast-evaluating devices

The Foster sunshine switch is an optical device which was already introduced operationally in the network of the United States in 1953 (Foster and Foskett, 1953). It consists of a pair of selenium photocells, one of which is shielded from direct sunshine by a shade ring. The cells are corrected so that in the absence of the direct solar beam no signal is produced. The switch is activated when the direct solar irradiance exceeds about 85 W m^{-2} (Hameed and Pittalwala, 1989). The position of the shade ring requires adjustments only four times a year to allow for seasonal changes in the Sun's apparent path across the sky.

8.2.5 Contrast evaluating and scanning devices

8.2.5.1 GENERAL

A number of different opto-electronic sensors, namely contrast-evaluating and scanning devices, were compared during the WMO Automatic Sunshine Duration Measurement Comparison at the Regional Radiation Centre of Regional Association VI in Hamburg from 1988 to 1989. The report of this comparison contains detailed descriptions of all instruments and sensors which participated in this event (WMO, in preparation).

8.2.5.2 SOURCES OF ERROR

Either the distribution of cloudiness over the sky or solar radiation reflected by surroundings can influence the results because of both the different procedures to evaluate the contrast and the relatively large field-of-view angles of the cells in the arrays used. Silicon photovoltaic cells without filters typically have the maximum responsivity in the near-infrared and the results, therefore, depend on the spectrum of the direct solar radiation.

Since the relatively small, slit-shaped, rectangular field-of-view angles of this device differ considerably from the circular-symmetrical one of the reference pyrheliometer, the cloud distribution around the Sun can cause deviations from the reference values.

Because of the small field of view, an imperfect glass dome may be a special source of uncertainty. The spectral responsivity of the sensor should also be considered in addition to solar elevation error. At present, only one of the commercial recorders using a pyroelectric detector is thought to be free of spectral effects.

8.3 Exposure of sunshine detectors

The three essential aspects for the correct exposure of sunshine detectors are:

- (a) The detectors should be firmly fixed to a rigid support. This is not required for the SONiE sensors which are designed also for use on buoys;

- (b) The detector should provide an uninterrupted view of the Sun at all times of the year throughout the whole period when the Sun is more than 3° above the horizon. This recommendation can be modified in the following cases:

- (i) Small antennas or other obstructions of small angular width ($\leq 2^\circ$) are acceptable if no alternative site is available. In this case, the position, elevation, and angular width of obstructions should be well documented and the potential loss of sunshine hours during particular hours and days should be estimated by the astronomical calculation of the apparent solar path;
 - (ii) In mountainous regions (valleys, for instance), the natural obstructions are acceptable as a factor of the local climate and should be well documented, as mentioned above;
- (c) The site should be free of surrounding surfaces which could reflect a significant amount of direct solar radiation to the detector. The reflected radiation can influence mainly the results of the contrast measuring devices. To overcome this interference, white paint should be avoided and nearby surfaces should either be kept free of snow or screened.

The adjustment of the detector axis is mentioned above. For some detectors, the manufacturers recommend tilting the axis, depending on the season.

8.4 General sources of error

The uncertainty of sunshine duration recorded by different types of instrument and methods is demonstrated as deviations from reference values in WMO (in preparation) for the weather conditions of Hamburg (Germany) in 1988–1989.

The reference values are also somewhat uncertain because of the uncertainty of the calibration factor of the pyrheliometer used and the dimensions of its field-of-view angle (dependency on the aureole). For single values, the time constant should also be considered.

General sources of uncertainty are:

- (a) The calibration of the recorder (adjustment of the irradiance threshold equivalent (section 8.5));
- (b) The typical variation of the recorder response due to meteorological conditions (e.g. temperature, cloudiness, dust) and the position of the Sun (e.g. errors of direction, solar spectrum);
- (c) The misadjustment and instability of important parts of the instrument;
- (d) The simplified or erroneous evaluation of the values measured;
- (e) Erroneous time-counting procedures;
- (f) Low quality of maintenance.

8.5 Calibration

The following general remarks are appropriate before describing various calibration methods:

- (a) No standardized method to calibrate *SD* detectors is available;
- (b) For outdoor calibrations, the pyrheliometric method has to be used to obtain reference data;
- (c) Because of the differences between the design of the *SD* detectors and the reference instrument, as well as with regard to the natural variability of the measuring conditions, calibration results have to be determined by long-term comparisons (some months);
- (d) Generally the calibration of *SD* detectors requires a specific procedure to adjust their threshold value (electronically for opto-electric devices, by software for the pyranometric systems);
- (e) For opto-electric devices with an analogue output, the duration of the calibration period should be relatively short;
- (f) The indoor method (using a lamp) is recommended primarily for regular testing of the stability of field instruments;
- (g) Examples of comparison results for different types of sunshine duration measurement methods (including the seasonal uncertainty) are presented in WMO (in preparation).

8.5.1 Outdoor methods

8.5.1.1 COMPARISON OF SUNSHINE DURATION DATA

Reference values SD_{ref} have to be measured simultaneously with the sunshine duration values SD_{cal} of the detector to be calibrated. The reference instrument used should be a pyrheliometer on a solar tracker combined with an irradiance threshold discriminator (section 8.1.4). Alternatively, a regularly recalibrated sunshine recorder of selected precision may be used. Since the requirement for accuracy of the sunshine threshold of a detector varies with the meteorological conditions (section 8.1.3), the comparison results must be derived statistically from datasets covering long periods.

If the method is applied to the total dataset of a period (with typical cloudiness conditions), then the first calibration result is the ratio $q_{tot} = \sum_{tot} SD_{ref} / \sum_{tot} SD_{cal}$.

For $q > 1$ or $q < 1$, the threshold equivalent voltage has to be adjusted to lower and higher values, respectively. Since the amount of the required adjustment is not strongly correlated to q_{tot} , further comparison periods are necessary to validate iteratively the approach to the ideal threshold by approximation of $q_{tot} = 1$. The duration of a total calibration period may be three to six months in the European mid-latitudes. Therefore, the facilities to calibrate network detectors should permit the calibration of several detectors simultaneously. (The use of q_{tot} as a correction factor for the $\sum SD$ values gives reliable results only if the periods to be evaluated have the same cloud formation as during the calibration period. Therefore, this method is not recommended).

If the method is applied to datasets which are selected according to special measurement conditions (e.g. cloudiness, solar elevation angle, relative sunshine

duration, daytime), then it may be possible, for instance, to find factors $q_{sel} = \sum_{sel} SD_{ref} / \sum_{sel} SD_{cal}$ statistically for different types of cloudiness. The factors could be used to correct datasets for which the cloudiness is clearly specified, too.

On the other hand, an adjustment of the threshold equivalent voltage is recommendable, especially if q_{sel} values for worse cloudiness conditions (such as Cirrus and Altostratus) are considered. An iterative procedure to validate the adjustment is also necessary; depending on the weather, some weeks or months of comparison may be needed.

8.5.1.2 COMPARISON OF ANALOGUE SIGNALS

This method is restricted to *SD* detectors having an analogue output which responds linearly to the received direct solar irradiance, at least in the range $< 500 \text{ W m}^{-2}$. The comparison between the reference irradiance measured by a pyrheliometer and the simultaneously measured analogue output should be performed at cloudless hours or other intervals with slowly variable direct solar irradiance below 500 W m^{-2} .

The linear regression analysis of such a dataset generates a best-fit line from which the threshold equivalent voltage at 120 W m^{-2} can be derived. If this calibration result deviates from the certified voltage by more than ± 20 per cent, then the threshold of the detector should be adjusted to the new value.

For detectors with a pronounced spectral response, the measured data at low solar-elevation angles around 120 W m^{-2} should be eliminated because of the stronger non-linearity caused by the spectrum unless the threshold voltage at sunrise and sunset is of special interest. The threshold equivalent voltage has to be extrapolated from higher irradiance values.

8.5.1.3 MEAN EFFECTIVE IRRADIANCE THRESHOLD (MEIT) METHOD

The so-called MEIT method (WMO, in preparation) is based on the determination of an hourly mean effective irradiance threshold I_m for the detector to be calibrated.

As a first step of this method, *SD* values $SD_{ref}(h_k, I(n))$ have to be determined from computer-controlled pyrheliometric measurements for hours h_k and fictitious threshold irradiances $I(n)$ between 60 and 240 W m^{-2} (that means that $I(n) = (60 + n) \text{ W m}^{-2}$ with $n = 0, 1, 2, \dots, 180$). As a second step, the hourly *SD* value $SD(h_k)$ of the detector has to be compared with the $SD_{ref}(h_k, I(n))$ to find the special $n = n_k$ for which $SD(h_k)$ equals $SD_{ref}(h_k, I(n_k))$. $I(n_k)$ represents the MEIT value of the hour h_k : $I_m(h_k) = (60 + n_k) \text{ W m}^{-2}$. If n_k is not found directly, then it has to be interpolated from adjacent values.

The third step is finally the adjustment of the threshold equivalent voltage of the recorder if the relative deviation between a mean MEIT value I_m and the ideal threshold 120 W m^{-2} is larger than ± 20 per cent. The mean value should be a monthly average, for instance, because of the large spread of the deviations of hourly MEIT values.

The method is not applicable to hours with dominant fast threshold transitions; the average gradient of an hour should be lower than $5 \text{ W m}^{-2} \text{ s}^{-1}$. The MEIT values are not representative for the total dataset of the calibration period.

8.5.2 Indoor method

Since the simulation of the distribution of direct and diffuse solar fluxes is difficult indoors, only a "spare calibration" can be recommended which is applicable for SD detectors with an adjustable threshold equivalent voltage. The laboratory test equipment consists of a stabilized radiation source (preferably with an approximated solar spectrum) and a stand for a precise local adjustment of the SD detector as well as of an SD detector — carefully calibrated outdoors — which is used as reference. Reference and test detectors should be of the same model.

At the beginning of the test procedure, the reference detector is positioned precisely in the beam of the lamp so that 120 W m^{-2} is indicated by an analogue output or by the usual "sunshine switch". Afterwards, the reference device is replaced precisely by the test device whose threshold voltage has to be adjusted to activate the switch or to get a 120 W m^{-2} equivalent. The repeatability of the results should be tested by further exchanges of the instruments.

8.6 Maintenance

The required maintenance routine for technicians consists of:

- (a) Cleaning. The daily cleaning of the respective entrance windows is necessary for all detectors, especially for scanning devices with small field-of-view angles. Instruments without equipment to prevent dew and frost should be cleared more than once on special days;
- (b) Checking. The rotation of special (scanning) parts as well as the data-acquisition system should be checked daily;
- (c) Exchanges. In Campbell-Stokes sunshine recorders, the burn card has to be exchanged daily; in other devices, the appropriate data carriers have to be replaced regularly;
- (d) Adjustments. Adjustments are required if a seasonal change of the tilt of the detector is recommended by the manufacturer, or possibly after severe storms.

Special parts of the detectors and of the data-acquisition systems used should undergo maintenance by trained technicians or engineers according to the appropriate instruction manuals.

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