Upcoming Changes of International Standards for the Classification of Radiometers

Stefan Wilbert, Wolfgang Finsterle, Aron Habte, Richard Meyer, Jorge Lezaca, Norbert Geuder

PVPMC workshop, Freiburg, 24.10.16
Overview

• Motivation
• Status and timeline of standardization activities
• **Updates in ISO 9060**
  • Updates in new ASTM classification standard(s)
• Conclusion and open issues
Motivation

- Radiometer classes are helpful for instrument selection (comparability, tenders)
- So far two classification systems:
  - “ISO 9060 Solar energy — Specification and classification of instruments for measuring hemispherical solar and direct solar radiation”
  - WMO CIMO guide classes (similar, not identical)
- ISO 9060 is 26 years old & partly outdated, WMO classes linked to ISO 9060
  - E.g. only conventional thermopiles & absolute cavity radiometers covered
  - Fast thermopiles with diffusors & Si-sensors are excluded, but frequently used
    - the better choice for some applications
      - **Faster** temporal response
      - Diffusor as outermost entrance window reduces **soiling effect**
  - **Costs** per station
    ⇒ Revision of ISO 9060 + new standard(s) in ASTM
- **Today:** option to give feedback / acceptance needed
Status and timeline

ISO 9060 revision:
- Draft created in 2015
- Draft International Standard (DIS) will be submitted & distributed to national standardization bodies for ballot in November 2016

ASTM
- Draft in spring 2015
- Then further discussions started
- Next drafts and ballots expected soon
Updates in ISO 9060

Topic 1: Spectral errors / fast response sensors
Topic 2: Correction functions
Topic 3: Shading structures
Topic 1: Spectral errors / fast response sensors

- Fast sensors with response time below one second mostly excluded, because **spectral selectivity** requirements cannot be reached by Si-sensors & many sensors with diffusor disks
- **Spectral selectivity, ISO 9060 1990 version** = “Percentage deviation of the product of spectral absorptance & spectral transmittance from the corresponding mean within 0.35 & 1.5μm”
  - Strict limits: 3% to 10% (pyra.), 0.5% to 5% (pyrh.)
- **Spectral selectivity ≠ spectral error**

The spectral irradiance error is the error introduced by the change in the spectral distribution of the incident solar radiation & the difference between the spectral response of the radiometer with respect to a completely homogeneous spectral response from 0.25 to 4 μm.
Suggestion for fast sensors as solid state sensors & fast thermopiles with diffusor disks

• Add classes that do not have any requirement for spectral selectivity so that fast sensors are included (next slide)

• Define spectral error & state that the spectral selectivity is not the spectral error.

• Work towards an accepted procedure for the calculation of the spectral error & include it in a future revision (not in this one).
<table>
<thead>
<tr>
<th>Specification</th>
<th>Sub-second sensors category</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Response time</strong>—time for 95 % response</td>
<td></td>
</tr>
<tr>
<td><strong>Zero off-set:</strong></td>
<td></td>
</tr>
<tr>
<td>a) response to 200 W m$^{-2}$ net thermal radiation (ventilated)</td>
<td>+ 15 W m$^{-2}$</td>
</tr>
<tr>
<td>b) response to 5 K h$^{-1}$ change in ambient temperature</td>
<td>$\pm$ 4 W m$^{-2}$</td>
</tr>
<tr>
<td>c) complete zero off-set including the effects a), b) and other sources</td>
<td>$\pm$ 22 W m$^{-2}$</td>
</tr>
<tr>
<td><strong>Non-stability:</strong> percentage change in responsivity per year</td>
<td>$\pm$ 2%</td>
</tr>
<tr>
<td><strong>Non-linearity:</strong> percentage deviation from the responsivity at 500 W m$^{-2}$ due to the change in irradiance within 100 Wm$^{-2}$ to 1000 W m$^{-2}$</td>
<td>$\pm$ 1%</td>
</tr>
<tr>
<td><strong>Directional response (for beam radiation):</strong> the range of errors caused by assuming that the normal incidence responsivity is valid for all directions when measuring from any direction a beam radiation whose normal incidence irradiance is 1000 Wm$^{-2}$</td>
<td>$\pm$ 30 W m$^{-2}$</td>
</tr>
<tr>
<td><strong>Spectral selectivity:</strong> [adapted definition, but not relevant here =&gt; next slide]</td>
<td>See NOTE 13</td>
</tr>
<tr>
<td><strong>Temperature response:</strong> percentage deviation due to change in ambient temperature within the interval from -10°C to 40°C relative to the signal at 20°C</td>
<td>$\pm$ 2%</td>
</tr>
<tr>
<td><strong>Tilt response:</strong> percentage deviation from the responsivity at 0° tilt (horizontal) due to change in tilt from 0° to 180° at 1000 W m$^{-2}$ irradiance</td>
<td>$\pm$ 2%</td>
</tr>
</tbody>
</table>

**Accuracy under real conditions with application of measurement best practices for 1 min average measurement (95% confidence level)**: 8% tbd 20%
Suggestion for spectrally flat sensors

- Change definition of spectral selectivity for spectrally flat sensors
  - clearer & applicable for all technologies: “spec. abs.* spec. trans.”
- ISO’s 0.35µm to 1.5µm vs. WMO’s range from 0.3µm to 3µm with even stricter limits

*Spectral selectivity:* Maximum percentage deviation of the spectral responsivity in the wavelength intervals given below from the mean spectral responsivity within 0.35µm & 1.5µm

a) 0.35µm to 1.5µm -> same limits as so far (3% to 10% (pyra.), 0.5% to 5% (pyrh.))

b) Intervals from 0.3µm to 0.35µm and from 1.5µm to 2.6µm -> less strict limits
## Pyranometer classes pt 2

<table>
<thead>
<tr>
<th>Spectrally flat sensors (category SF)</th>
<th>SF***</th>
<th>SF**</th>
<th>SF*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secondary standard</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First class</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Second class</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Identical to SS sensor specs**

**Roughly corresponding class from ISO 9060 (1990)**

### Specifications

<table>
<thead>
<tr>
<th>Specifications</th>
<th>SF***</th>
<th>SF**</th>
<th>SF*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Response time</strong>—time for 95 % response</td>
<td>&lt;15 s</td>
<td>&lt;30 s</td>
<td>&lt;30 s</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Zero off-set:</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a) response to 200 W m(^{-2}) net thermal radiation (ventilated)</td>
<td>+ 7Wm(^{-2}) ± 2Wm(^{-2}) ± 10Wm(^{-2})</td>
<td>+ 15Wm(^{-2}) ± 4Wm(^{-2}) ± 21Wm(^{-2})</td>
<td>+ 30Wm(^{-2}) ± 8Wm(^{-2}) ± 41Wm(^{-2})</td>
</tr>
<tr>
<td>b) response to 5 K h(^{-1}) change in ambient temperature</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c) complete zero off-set including the effects a), b) and other sources</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Non-stability: percentage change in responsivity per year</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>± 0,8%</td>
<td>± 1,5%</td>
<td>± 3%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Non-linearity: percentage deviation from the responsivity at 500 W m(^{-2}) due to the change in irradiance within 100 Wm(^{-2}) to 1 000 W m(^{-2})</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>± 0,5%</td>
<td>± 1%</td>
<td>± 3%</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Directional response (for beam radiation): the range of errors caused by assuming that the normal incidence responsivity is valid for all directions when measuring from any direction a beam radiation whose normal incidence irradiance is 1000 Wm(^{-2})</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>± 10Wm(^{-2})</td>
<td>± 20Wm(^{-2})</td>
<td>± 30Wm(^{-2})</td>
<td></td>
</tr>
</tbody>
</table>

... continued on next slide

- **Italics** = definition changed
- **Red**: limit changed or new
- **Blue**: New! Required to include arbitrary technologies
## Pyranometer classes pt 2

<table>
<thead>
<tr>
<th>Spectrally flat sensors (category SF)</th>
<th>SF***</th>
<th>SF**</th>
<th>SF*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identical to SS sensor specs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roughly corresponding class from ISO 9060 (1990)</td>
<td>Secondary standard</td>
<td>First class</td>
<td>Second class</td>
</tr>
</tbody>
</table>

### Specifications

**Spectral selectivity:** Maximum percentage deviation of the spectral responsivity in the wavelength intervals given below from the mean spectral responsivity within 0,35 µm and 1,5 µm

- a) 0,35µm to 1,5µm: ± 3 %, ± 5%, ± 10%
- b) Intervals from 0,3µm to 0,35µm and from 1,5µm to 2,6µm: ± 12 %, ± 20 %, ± 40 %

**Temperature response:** percentage deviation due to change in ambient temperature within the interval from - 10°C to 40°C relative to the signal at 20°C

<table>
<thead>
<tr>
<th></th>
<th>SF***</th>
<th>SF**</th>
<th>SF*</th>
</tr>
</thead>
<tbody>
<tr>
<td>± 2%</td>
<td>± 4%</td>
<td>± 8%</td>
<td></td>
</tr>
</tbody>
</table>

**Tilt response:** perc. deviation from the responsivity at 0° tilt (horizontal) due to change in tilt from 0° to 180° at 1000 W m⁻² irradiance

<table>
<thead>
<tr>
<th></th>
<th>SF***</th>
<th>SF**</th>
<th>SF*</th>
</tr>
</thead>
<tbody>
<tr>
<td>± 0,5%</td>
<td>± 2%</td>
<td>± 5%</td>
<td></td>
</tr>
</tbody>
</table>

**Accuracy under real conditions with application of measurement best practices for 1min average measurement (95 % confidence level)**

<table>
<thead>
<tr>
<th></th>
<th>SF***</th>
<th>SF**</th>
<th>SF*</th>
</tr>
</thead>
<tbody>
<tr>
<td>3%</td>
<td>8%</td>
<td>tbd</td>
<td>20%</td>
</tr>
</tbody>
</table>

- **Italics** = definition changed
- **Red:** limit changed or new
- **Blue:** New! Required to include arbitrary technologies
- **Purple:** ≠ WMO limit
Comments on the proposed classification tables

• One sensor can be in two categories!
  • Example:
    • A thermopile sensor with a fast response time can fulfill both SF** and SS+.
    • A tender could explicitly ask for such a sensor in two classes

• Same concept shown for pyranometers also applied to pyrheliometers
Topic 2: Correction functions

• … for systematic errors as directional errors, temperature dependence, … are frequently used
• Corrections can greatly improve the signal
• Question: Which signal must be used for the classification?

Draft International Standard (as of 19.10.2016):
• The **corrected signal can be used for the classification** if the corrected signal is given by the system
  “sensor + logger / processor / software” that is offered by the instrument provider.
• If the user must implement the corrections on his own the corrections cannot be used for the classification.
Topic 3: Diffusometers

- Title of ISO 9060 is general:
  - “hemispherical radiation”
- Diffuse Horizontal Irradiance (DHI) is therefore included in scope
  - But no shading structures mentioned in ISO 9060

Suggestion:
- Define shown shading types in ISO 9060
- Not required: quantitative quality statements for shading types & classes of diffusometers
- This is the same concept as for pyrheliometers in ISO 9060
  - Trackers mentioned in ISO 9060, but quality & tracking errors not
Updates in ASTM

• Draft from 2015 mostly in line with ISO 9060 update
  • But no diffusometers

• New discussions after extension of group and work on ISO 9060:
  • Roughly the same discussions as in before the previous draft again
  • Two separate standards for fast response sensors and spectrally flat sensors preferred
    • Not as in ISO, but no contradiction
  • No diffusometers
    • Not as in ISO, but no contradiction
  • Some participants want to remove correction functions
    • Would be a contradiction to ISO
Conclusion and open issues

• New standards in ASTM and ISO for classification will be published in the next years
  • WMO classes will be adjusted to new ISO 9060 classes later

• Some open issues remain
  • Contradictions between ASTM and ISO must be avoided
  • Acceptance is required

• Comments that can help to resolve open issues or identify others
  • …are highly welcome
  • …until first week of November for Draft International Standard (DIS)
  • Later comments welcome for revision of DIS and final standard
Thank you for your attention!

stefan.wilbert@dlr.de

We thank the German Federal Ministry for Economic Affairs and Energy and the Helmholtz Association for the financial support within the projects INS1268 and Desergy.