The World Calibration Center for UV (WCC-UV)

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Outline

- The World Radiation Center of WMO
- Quality Assurance of solar UV measurements
- The Top of Atmosphere solar spectrum measured from the surface using QASUME
The Physikalisches-Meteorologisches Observatorium Davos and World Radiation Center (PMOD/WRC)

BIPM CCPR

WMO (World Meteorological Organization)

Commission for Instruments and Methods of Observations (CIMO)

World Radiation Center (WRC)

Solar Radiometry Section (WRC-SRS)
since 1971

Infrared Radiometry Section (WRC-IRS)
since 1996

World Optical Depth Research and Calibration Center (WORCC)
since 2004

World Calibration Center for UV (WCC-UV)
since 2013

2 CMC's

4 CMC's

Designated Institute for "Solar Irradiance"
Solar UV monitoring stations traceable to WCC-UV

Total stations
QASUME  >50
Broadband radiometer  >130
Comparison of solar spectra

\[ R(\lambda) = \frac{DUT(\lambda)}{QASUME(\lambda)} \]

- Same wavelength scale
- Uniform slit width (1 nm default)
QASUME comparisons
Spectral Solar UV Quality Assurance Program QASUME

“Quality Assurance of Spectral Ultraviolet Measurements in Europe through the development of a transportable unit “

- 79 site visits
- 247 spectroradiometer intercomparisons

On site comparison with the portable QASUME reference spectroradiometer

\[
\frac{DUT}{QASUME} = -3 \pm 11\%
\]

Status 2002 - 2018

Traceability chain for spectral irradiance

Detector-based
- cw-laser sources
- Cryogenic radiometer
- Si-trap detector + aperture
- Filter Radiometer
- Blackbody + aperture
- Transfer standards

Source-based
- Spectrally tuneable source
- Spectroradiometer

U=±1.1%
Spectral irradiance reference at WCC-UV

2004 - 2019

Long-term stability of ~0.2%
Validation of the WCC-UV irradiance scale

Detector-based

Cryogenic radiometer

Si-trap detector + aperture

cw-laser sources

Tunable lasers

Source-based

Spectrally tuneable source

Filter Radiometer

Blackbody + aperture

Transfer standards

Spectroradiometer

Source-based

Detector

Source

U=±0.3%

U=±1.1%
Validation of the WCC-UV irradiance scale

Detector-based
- Cryogenic radiometer
- Si-trap detector + aperture

Source-based
- cw-laser sources
- Spectrally tuneable source
- Transfer standards

Tunable lasers

U=±0.3%
U=±1.1%
Validation of the WCC-UV irradiance scale

TULIP – tunable laser setup

All measurements within ±1%
Determining the extraterrestrial solar spectral irradiance spectrum from the surface Traceable to SI

\[ I_\lambda = I_\lambda^0 e^{-\tau_\lambda m} \]
Measuring the ET SSI from the surface
What are the advantages / disadvantages?

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traceability to SI is possible</td>
<td>Limited wavelength range:</td>
</tr>
<tr>
<td>Repeated calibrations before, during, and after the measurements</td>
<td>• Only weakly absorbing atmospheric regions are accessible</td>
</tr>
<tr>
<td>Uncertainties are lower than what is currently achievable in space</td>
<td>• Need stable atmospheric conditions</td>
</tr>
<tr>
<td></td>
<td>• Depends (slightly) on an atmospheric model</td>
</tr>
</tbody>
</table>
Instrumentation

QASUME

Double monochromator spectroradiometer

Fourier Transform Spectroradiometer
How to get the extraterrestrial solar spectrum from the surface:

The Beer-Lambert law

\[ I_\lambda = I_\lambda^0 e^{-\tau_\lambda m} \]

\[ \log I_\lambda = \log I_\lambda^0 - \tau_\lambda m \]

\[ y = a - bx \]

The optical depth \( \tau \) is assumed constant during this period (half-day).
The high resolution extraterrestrial solar spectrum QASUMEFTS

- $300 \leq WL < 304.8$ nm: KittPeak normalised to QASUME
- $304.8 \leq WL < 379$ nm: FTS normalised to QASUME
- $379 \leq WL < 500$ nm: KittPeak normalised to QASUME

$U_{QASUME} = 2.0\% \ (k=2) \ \lambda > 300$ nm
With an FTS, the wavelength is inherently traceable to SI, $U_{\lambda}$ is estimated at 10 pm (0.01 nm)

Wavelength agreement between FTS and KittPeak is 1 pm
Comparison to a few space based solar spectra

- **Sciamachy**
  - Hilbig et al., 2017

- **SOLAR_ISS**
  - Meftah et al., 2016

- **ATLAS-3**
  - Thullier et al., 2003

- **SORCE SIM**
  - Harder et al., 2009

Gröbner et al., 2017
Summary

- PMOD/WRC follows the requirements for the competence of testing and calibration laboratories according to ISO/IEC 17025.
- PMOD/WRC is designated institute for solar irradiance of the Swiss Federal Office for Metrology METAS and signatory of the CIPM MRA.
- PMOD/WRC has submitted 6 Calibration and Measurement Capabilities (CMC) to the Key comparison database of the BIPM.

Global (direct) spectral solar UV irradiance measurements are traceable to SI with an expanded uncertainty (k=2) of 2% (1.3%).

### Uncertainty budget for spectral solar UV irradiance measurements

<table>
<thead>
<tr>
<th>Uncertainty Parameter</th>
<th>Relative Std Uncertainty %</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Global Solar Irradiance</td>
</tr>
<tr>
<td></td>
<td>QASUME</td>
</tr>
<tr>
<td>Radiometric calibration</td>
<td>0.55 (before 1.8)</td>
</tr>
<tr>
<td>250 W lamp stability (one year)</td>
<td>0.10 (±1.7%/2)</td>
</tr>
<tr>
<td>Nonlinearity ... From PMT or PC</td>
<td>0.25</td>
</tr>
<tr>
<td>ND filter transmission</td>
<td>n/a</td>
</tr>
<tr>
<td>Stability</td>
<td>0.20</td>
</tr>
<tr>
<td>Temperature Dependence, Entrance optic (±1%/2)</td>
<td>0.2 (temp-stability with max at 0.2%/2)</td>
</tr>
<tr>
<td>Angular Response (Clear Sky)</td>
<td>0.6 (±1%/2)</td>
</tr>
<tr>
<td>Angular Response (Overcast)</td>
<td>0.3 (±1%/2)</td>
</tr>
<tr>
<td>Repeatability (std noise)</td>
<td>(λ=310nm)</td>
</tr>
<tr>
<td>Repeatability (std noise)</td>
<td>(λ=300nm, SZA=75°)</td>
</tr>
<tr>
<td>Wavelength shift (after matSHC)</td>
<td>Δλ=0.02 nm</td>
</tr>
<tr>
<td>Combined Uncertainty</td>
<td>0.9 (overcast, SZA=65°, 0.8)</td>
</tr>
<tr>
<td>Expanded Uncertainty (k=2)</td>
<td>1.9 (overcast: 1.6)</td>
</tr>
</tbody>
</table>

Hülsen et al., Applied Optics, 2016