Near Infrared Ground-based Spectrum

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Outline

• Historical of the ground-based SSI
• Fundaments of the measurement
• Rationale for a ground based NIR campaign
• NIR campaign
  • Instrumentation
  • Calibration
  • Uncertainty budget
• Results comparison
## Historical of SSI ground-based measurements

<table>
<thead>
<tr>
<th>Site</th>
<th>Range</th>
<th>Instrument</th>
<th>Calibration standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arvesen 1969</td>
<td>Aircraft 12 Km</td>
<td>UV-Vis-NIR Spectrometer</td>
<td>On board secondary standard, traceable to NIST</td>
</tr>
<tr>
<td>Shaw 1982</td>
<td>MLO</td>
<td>UV-Vis-NIR 10-channel Radiometer</td>
<td>1000W lamps Traceable to NIST</td>
</tr>
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<td>Kindel 2001</td>
<td>MLO</td>
<td>UV-Vis-NIR Spectrometer</td>
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<tr>
<td>Gröbner 2001</td>
<td>MLO</td>
<td>Vis Brewer</td>
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<tr>
<td>Gröbner 2017</td>
<td>IZO</td>
<td>UV Spectrometer</td>
<td>PTB Blackbody</td>
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</table>

### Note

+ see G. Rottman poster about the TSI value APO network

IZO: Izaña Atmospheric Observatory. Canary Islands, 2373 m.a.s.l.
MLO: Mauna Loa Observatory. Hawaii, 3397 m.a.s.l

Prime sites for atmospheric observations
Absolute calibration centers of NASA AERONET (Aerosol RObotic NETwork)
Langley-Plot method: Retrieval of TOA quantities

Beer-Bouguer-Lambert Law

\[
E = E_0 \exp(-m\tau)
\]

\[
\log(E_i) = \log(E_0) - m_i \tau
\]

\[
Y_i = \alpha \cdot X_i + \beta
\]

Conditions of application

- Pristine and stable atmospheric conditions
- Absorption-free wavelength regions
- Constant optical depth
NIR absolute level: state of the art (2012)

High disagreement in the NIR
- Up to 10% at 1.6µm between SORCE and SOLAR/SOLSPEC
- No overlap of error bars
- Need for and independent measurements

Ground based-measurement using Langley-plot
- Sound methodology
- Low-cost mission
- Possibility of using high-altitude reference observatory (IZO)

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<td>Menang 2013</td>
<td>Camborne (UK)</td>
<td>NIR</td>
<td>FTIR</td>
</tr>
<tr>
<td><strong>CAVIAR</strong></td>
<td>88 m.a.s.l.</td>
<td></td>
<td>NPL standards</td>
</tr>
<tr>
<td>Bolsée et Pereira 2014</td>
<td>IZO</td>
<td>NIR</td>
<td>Spectrometer</td>
</tr>
<tr>
<td><strong>IRSPERAD</strong></td>
<td></td>
<td></td>
<td>PTB Blackbody</td>
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NIR absolute level: state of the art (2014)

Still high disagreement in the NIR
- New ground-based on lower stack of datasets
- Ground-based datasets not so well accepted in the SSI community
- Big discrepancy at 1.6μm remains
- No overlap of error bars
- Disagreement in the NIR remains
- Need for and independent measurements, again!

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*PYR-ILILOS*
Ground-based campaign

Izana Observatory (IZO) 2011
• 2373 masl
• 4-month campaign
• 4 FEL lamps, 2 relative calibrations
• PTB Black Body Calibration
• Spectrometer outdoors

Mauna Loa Observatory (MLO) 2016
• 3397 masl
• 20-day campaign
• 6 FEL lamps, 4 relative calibrations
• PTB Black Body Calibration
• Spectrometer indoors
• Hardware improvement

Spectrometer more robust to displacement
Ground-based campaign

**Spectrometer**
- **Type**: Double Czerny-Turner Plane grating configuration
- **Spectral range**: 600-2400 nm
- **Nominal Bandwidth**: 10 nm

**Detector**
- **Type**: PbS cell
- **Peak sensitivity**: 2.7 micron
Absolute calibration

PTB (Braunschweig, Germany) as primary standard of irradiance

\[ E = \varepsilon \frac{A}{d^2} \frac{c_1}{n^2 \lambda^5} \exp \left( \frac{c_2}{n \lambda T} \right) - 1 \]

emissivity \( \sim 0.9998 \pm 0.01\%
\)
d \( \sim 1384.05 \text{ m} \pm 0.04\%
\)
A \( \sim 111.388 \text{ mm}^2 \pm 0.04\%
\)
u(T) = 0.44 K, drift(T) < 0.5 K/hour

Two temperatures used for calibration

\[ 3016.5 \text{ K} \text{ and } 2847.6 \text{ K} \]
Relative calibration

Power OFF + transportation Lab ↔ Platform + Power ON

IZO 2011

MLO 2016
Uncertainties reduction

\[ E(\lambda) = S(\lambda) \cdot R(\lambda) \cdot K(\lambda) \]

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<tr>
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<th>Relative calibration: K</th>
<th>Uncertainty at 1000nm</th>
<th>Absolute Calibration: R</th>
<th>Unc (1000nm)</th>
<th>Solar Signal: S</th>
<th>Unc (1 micron)</th>
</tr>
</thead>
</table>
| IZO (2011)       | 4 lamps, 2 relative calibrations  
• Start campaign  
• End campaign | 0.44%                  | BB at 3016.5K          | 0.52%        |                 |                 |
| MLO (2016)       | 6 lamps, 4 relative calibrations  
• Start campaign  
• Mid-campaign x 2  
• End campaign    | 0.16%                  | BB at 3016.5K and 2847.5K | 0.45%        | Same response  | 0.20%          |

- Loss of response between end and beginning of campaign (~2% @ 1000nm)
- Spectrometer outdoors => Thermal correction for instrument response (up to 1% @ 1000nm)
- High-frequency relative calibration detected small measurable changes in instrument response
- Spectrometer indoors => No thermal correction for instrument response
Data selection and processing

- SZA calculated with Meeus algorithms
- SZA corrected for atmospheric refraction
- Air masses calculated with K&Y algorithm
- Data screened for clouds
- Selection for $R^2 \geq 0.9$

12 high-quality half-days

Kasten, F. and Young, A. T., Appl. Opt., 28, 4735
Derived from spectrometer SNR curve

\[ E(\lambda) = S(\lambda) \cdot R(\lambda) \cdot K(\lambda) \]
Circumsolar radiation

Radiance modeling with LibRadtran RTM
Parameters: Atmospheric conditions at MLO
• Pressure/Altitude
• Aerosol charge

\[ \text{CSI} \propto \text{SZA}, \lambda^{-1} \]
Sensitivity to non-constant aerosol optical depth

**AErosol RObotic NETwork data:**
https://aeronet.gsfc.nasa.gov/

**2 July 2016 AM**
\[ \lambda = 1020 \text{ nm} \]

**Log(E0)**
- **measured**
- **synthetic**

**Aerosol Optical Depth**

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**Legend:**
- **AOD(aeronet)**
- **measured LP**
- **synthetic LP**
- **True intercept**

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Flat-field of the entrance optics

Tracking accuracy

0.01 deg
Uncertainty budget on TOA irradiance

\[ E(\lambda) = S(\lambda). R(\lambda). K(\lambda) \]

1) Monte-Carlo method

\[ L.P. (m_i + u(m_i), E_i + u(E_i)) \Rightarrow E_0 \sim \text{Normal}(\langle E_0 \rangle, \sigma) \]

2) From linear regression algorithm*

\[ L.P.(m_i, u(m_i), E_i, u(E_i)) \Rightarrow (E_0, \tau, u(E_0), u(\tau)) \]

\[ u(E(1020nm)) = 0.4 \% \]

\[ \begin{align*}
  u(\text{AMF=2}) &= 0.04\% \\
  u(\text{AMF=4}) &= 0.19\% \\
  u(\text{AMF=8}) &= 0.79\%
\end{align*} \]

Results and NIR comparison

SOLSPEC SOLAR-ISS as reference spectrum

PYR-ILILOS: Pereira, N., Bolsée, et al., AMT 2018
TSIS: <2018-03-14 : 2018-11-15>
CAVIAR 2: Elsey et al., GRL, 2017
Conclusions

- PYR-ILIOS is the most robust ground-based NIR dataset
  - Robust Hardware
  - Intra-campaign recalibration strategy adapted to monitor eventual response changes
  - Recalibration frequency assures traceability to Black Body primary standard of irradiance

- Ground-based SSI gained visibility in the SSI community

- SOLAR-ISS replacing ATLAS3 as reference spectrum of the SOLSPEC instrument family

- Improved data processing of SCIAMACHY and SOLAR-ISS and TSIS agree with PYR-ILIOS

- Agreement of the absolute level in the NIR is growing, along with accuracy
\[ E = E_0 \cdot \exp(-m_R \tau_R - m_A \tau_A) \]

\[ m_R \approx m_A, \tau_R + \tau_A = \tau \]

\[ m = m(SZA) \]