Comprehensive characterization of RAMSES hyper-spectral radiometers

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A measurement of any kind is incomplete unless accompanied with an estimate of the uncertainty associated with that measurement.

Calibration Equation

The conversion from relative to physical units of the radiometric quantity $\mathcal{I}(\lambda)$ (either $E(\lambda)$ or $L(\lambda)$) at wavelength $\lambda$ is performed through

$$\mathcal{I}(\lambda) = C_\mathcal{I}(\lambda) I_f(\lambda) N(\lambda) DN(\mathcal{I}(\lambda))$$

where $DN(\mathcal{I}(\lambda))$ indicates the digital output corrected for the dark value, $C_\mathcal{I}(\lambda)$ is the in–air absolute calibration coefficient (i.e., the absolute responsivity), $I_f(\lambda)$ is the immersion factor accounting for the change in responsivity of the sensor when immersed in water with respect to air, and $N(\lambda)$ corrects for any deviation from the ideal performance of the measuring system.

In the case of an ideal radiometer $N(\lambda)=1$, but in general

$$N(\lambda) = N_i(i(\lambda)) N_j(j(\lambda)) ... N_k(k(\lambda))$$

where $N_i(i(\lambda))$, $N_j(j(\lambda))$, ..., and $N_k(k(\lambda))$ are correction terms for different factors affecting the non-ideal performance of the considered radiometer (e.g., non-linearity, temperature response, polarization sensitivity, stray-light perturbations, spectral response, geometrical response, ...).
RAMSES dual-field of view above-water system

System for the simultaneous determination of $L_w$ with 3 and 7 degrees full-angle field of view
RAMSES (TriOS) radiometers

- RAMSES-ACC irradiance sensors rely on a cosine collector of 3.5 mm radius, while RAMSES-ARC radiance sensors have a condenser lens defining a full-angle field-of-view of ~7 degrees.

- The foreoptics is coupled to a fiber bundle that feeds a ZEISS (Oberkochen, Germany) Monolithic Miniature Spectrometer (MMS-1) built on the Hamamatsu (Ichino-cho, Japan) S3904 256-channel NMOS array.

- The integration time can be set between 4 ms and 8192 ms.

- The spectral resolution is approximately 10 nm with average spectral sampling of 3.3 nm in the 320 nm–950 nm interval.
Immersion Factor $I_f$ (irradiance)

Schematic of the JRC ARCS system including lamp, water-tank and rotary stage

In-air and in-water spectral results

Angular response normalized at 20°

\[ E_N(\phi, \theta, \lambda) = \frac{E(\phi, \theta, \lambda) \cos(20)}{E_0(\phi, 20, \lambda)} \]

Cosine error

\[ f_c(\phi, \theta, \lambda) = \left[ \frac{E_N(\phi, \theta, \lambda)}{\cos(\theta)} - 1 \right] \]
Cosine error for a number of RAMSES irradiance sensors

Temperature response

Change in response with temperature

Temperature coefficient

Temperature response: results

**Joint Research Centre**

**Measurement configurations applied for the determination the polarimetric characteristics of radiance sensors**


**Flow diagram for the determination of the polarimetric characteristics of a radiometer**

\[
\begin{align*}
\text{SOURCE} & \rightarrow \text{POLARIZER} \quad P(s, d, p, q) \\
S & \rightarrow S_P = P \cdot S \\
\text{ROTOR} \quad M(\phi) & \rightarrow S_{MP} = M \cdot S_P \\
\text{RADIOMETER} \quad r(R_{00}, r_1, r_2, r_3), \mathcal{R} & \rightarrow DN = r \cdot S_{MP} \cdot \mathcal{R}
\end{align*}
\]

**Difference in polarization sensitivity across rotation planes of RAMSES hyperspectral radiometers**

**Impact of polarization sensitivity in Rrs measurements performed with RAMSES hyperspectral radiometers**
Straylight effects

Example of uncertainty budget

Uncertainty budget (in percent) for \( L_w \) determined from in-water profile data (hyperspectral radiometer)

<table>
<thead>
<tr>
<th>Uncertainty source</th>
<th>443</th>
<th>555</th>
<th>665</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute calibration of ( L_u )</td>
<td>2.7</td>
<td>2.7</td>
<td>2.7</td>
</tr>
<tr>
<td>Immersion factor</td>
<td>0.2</td>
<td>-0.6</td>
<td>0.2</td>
</tr>
<tr>
<td>Temperature response (+5C)</td>
<td>+0.2</td>
<td>-0.3</td>
<td>-0.7</td>
</tr>
<tr>
<td>Polarization sensitivity</td>
<td>+0.1</td>
<td>+0.2</td>
<td>+0.4</td>
</tr>
<tr>
<td>Stray-light effects</td>
<td>-1.0</td>
<td>+0.5</td>
<td>+0.5</td>
</tr>
<tr>
<td>Nonlinearity</td>
<td>-0.0</td>
<td>-1.0</td>
<td>-0.2</td>
</tr>
<tr>
<td>Self-shading correction</td>
<td>0.3</td>
<td>-1.2</td>
<td>-0.8</td>
</tr>
<tr>
<td>Environmental effects</td>
<td>2.1</td>
<td>2.1</td>
<td>3.2</td>
</tr>
<tr>
<td>Statistical sum</td>
<td>3.4</td>
<td>4.2</td>
<td>4.3</td>
</tr>
</tbody>
</table>

\[ \mathcal{I}(\lambda) = C \mathcal{I}(\lambda) I_f(\lambda) \mathcal{N}(\lambda) DN(\mathcal{I}(\lambda)) \]

The above table includes contributions related to temperature response, polarization sensitivity, stray-lights, nonlinearity, i.e., \( \mathcal{N}(\lambda) \neq 1 \) (the radiometer does not have ideal performance).

Neglecting corrections may lead to an obvious underestimate of uncertainties. Noteworthy, compensation processes may minimize systematic effects for given measurement conditions with potential spectral impacts.
Conclusions

A detailed characterization of field radiometers is the only way to ensure a comprehensive quantification of uncertainties. In fact, uncorrected systematic effects resulting from instrument miss-performance may differently affect uncertainties during diverse measurement conditions.

Full instrument characterizations are definitively essential for those instruments supporting key radiometric applications (e.g., system vicarious calibration or validation activities for climate applications).

Thanks