TARTU OBSERVATORY
space research centre

Challenges in calibration of in-situ Ocean Colour Radiometers

Viktor Vabson, Andrew Banks, Rüdiger Heuermann, Ilmar Ansko, Joel Kuusk, Riho Vendt, Anu Reinart, Agnieszka Bialek, Claire Greenwell, Barry Scott

Outline

1. Calibration uncertainty of radiometric sensors
2. Contributions needing attention
   a) Evaluating stability of standard lamps
   b) Correcting spectra for non-linearity and temperature effects
   c) Evaluating the contribution from alignment of instruments
   d) Comparison calibration of the field radiometers
3. Conclusions

Uncertainty components

1. Standard lamp
   1.1 Calibration certificate (often dominating contribution)
   1.2 Lamp ageing
   1.3 Interpolation
   1.4 Shunt
   1.5 Lamp current
2. Diffuse reflection plaque (certificate, correction if needed)
3. Alignments
   3.1 Distance
   3.2 Reproducibility (lamp, plaque, sensor)
4. Random effects (repeatability of spectra, and dark signal)
5. Correcting for non-linearity
6. Correcting for temperature

Critical uncertainty components from the SIRREX-7 experiments.

S. B. Hooker, S. McLean, J. Sherman, M. Small, G. Lazin, G. Zibordi, J.W. Brown, "The Seventh SeaWiFS Intercalibration Round-Robin Experiment (SIRREX-7), TM-2003- 206892, vol. 17, NASA, Feb. 2002.

Uncertainty component	Irradiance, relative uncertainty, %		
	Best	Typical	Moderate
Primary Lamp Standard	1	1	1
Secondary Lamp Standard	0	1	1
Excessive Lamp Age	0	0	1
Excessive Lamp Wear	0	0	2
Positioning Discrepancies	0	1,5	1,5
Unseasoned Lamp	0	0	0,5
Low Operating Current	0	0	1
Mechanical Setup	0,5	0,5	0,5
Rotational Discrepancies	0	0,5	0,5
Alignment Discrepancies	0	0,5	0,5
Inadequate Baffling	0	0,5	0,5
Combined uncertainty	1,1	2,3	3,4
Expanded uncertainty	2,2	4,6	6,8

Ranking labs and handling uncertainty components

In the SIRREX-7 experiments the calibration labs were ranked as primary, secondary, or tertiary based on the difficulty of improving. Uncertainty of tertiary labs is easier to reduce than secondary or primary labs.

It is advisable to handle uncertainty in the order of decreasing importance:

Calibration of lamps and plaques, and ageing effects

Operation of lamps: accuracy of lamp current

Distance and alignment: lamp – plaque – radiometer

Corrections: linearity, ambient temperature, stray light

Lamp ageing

The irradiance produced by standard lamps changes with burning time.

Before calibration the lamps are usually pre-selected, and pre-aged.

The drift of the new FEL lamps is less than 0.01 %/h, but unpredictable stepwise changes up to ±1 % still may occur.

Therefore, it is advisable to have a method for evaluation of drift, and for regular check of the lamps:

a) Use of monitor radiometer concurrently with lamp
b) Analysis of calibration history if available
c) Using at least two standard lamps for each sensor calibration
d) Regular stability check of lamps with filter radiometer

Evaluation of ageing

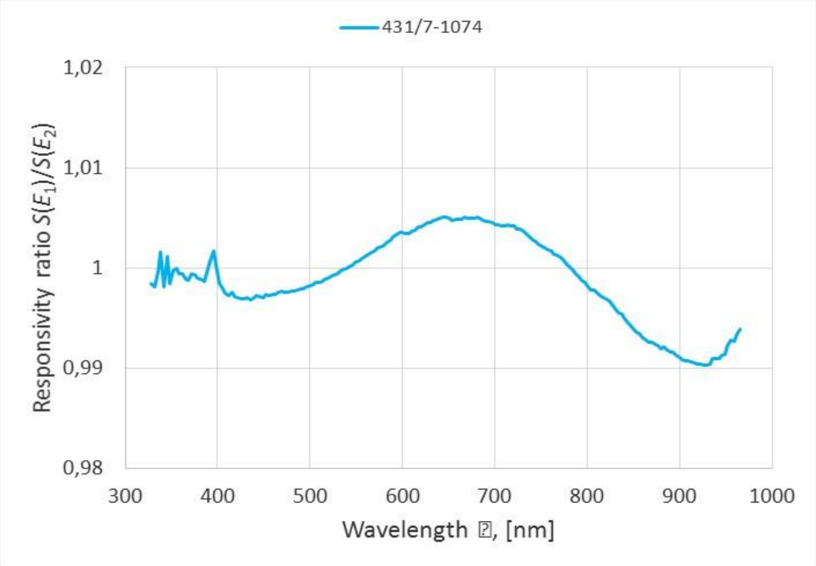
Ratio of spectra measured with different lamps reveals:

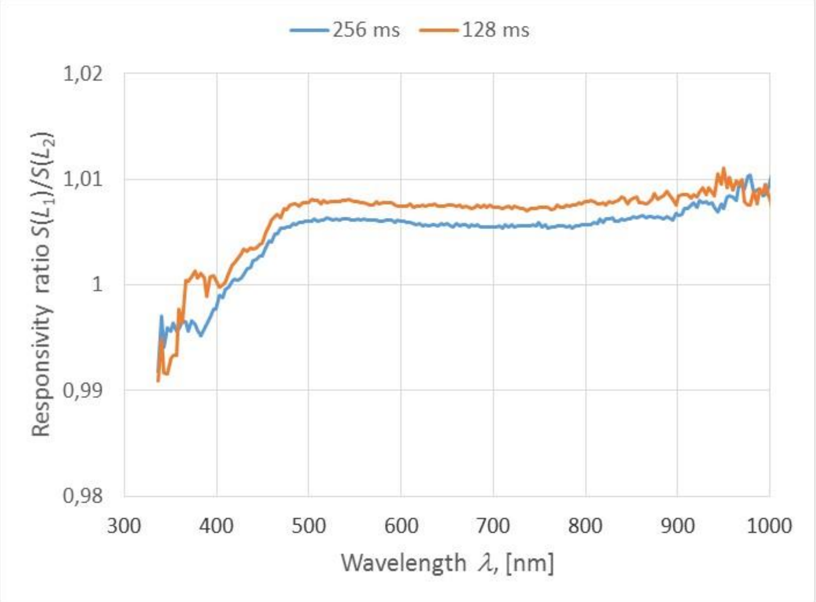
- Drift difference of lamps;
- Difference of calibration sources.

Procedure for data handling:

1) Spectra are averaged
2) Uncertainty is suitably increased
3) If difference is large the lamps should be recalibrated

Before measurement, for each lamp an alignment is needed.





Evaluation of ageing

Usual uncertainty estimate due to lamp ageing: drift about 0.6 % after 50 working hours. As example, for a lamp with 40 hours working time:

$$u(lamp\ aging) = \frac{0.6\ \%}{\sqrt{3}} \frac{40}{50} = 0.28\ \%$$

Similar procedure is used also when for calibration two lamps are used.

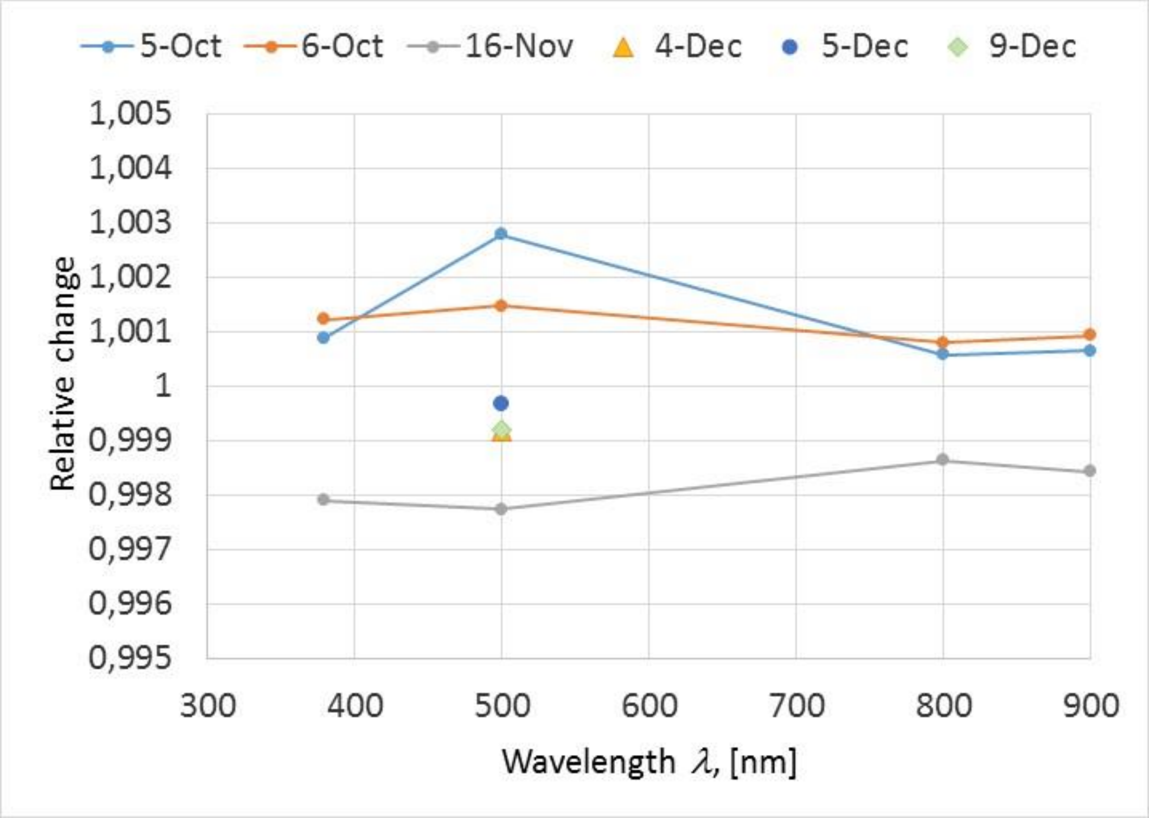
The most effective method for revealing a drift of the lamp is regular check of the lamps with filter radiometer.

Advantages of the method:

1. Measurement data can easily be used for uncertainty evaluation
2. Stability of filter radiometer is significantly surpassing the lamp
3. New alignment of the measurement system is not required

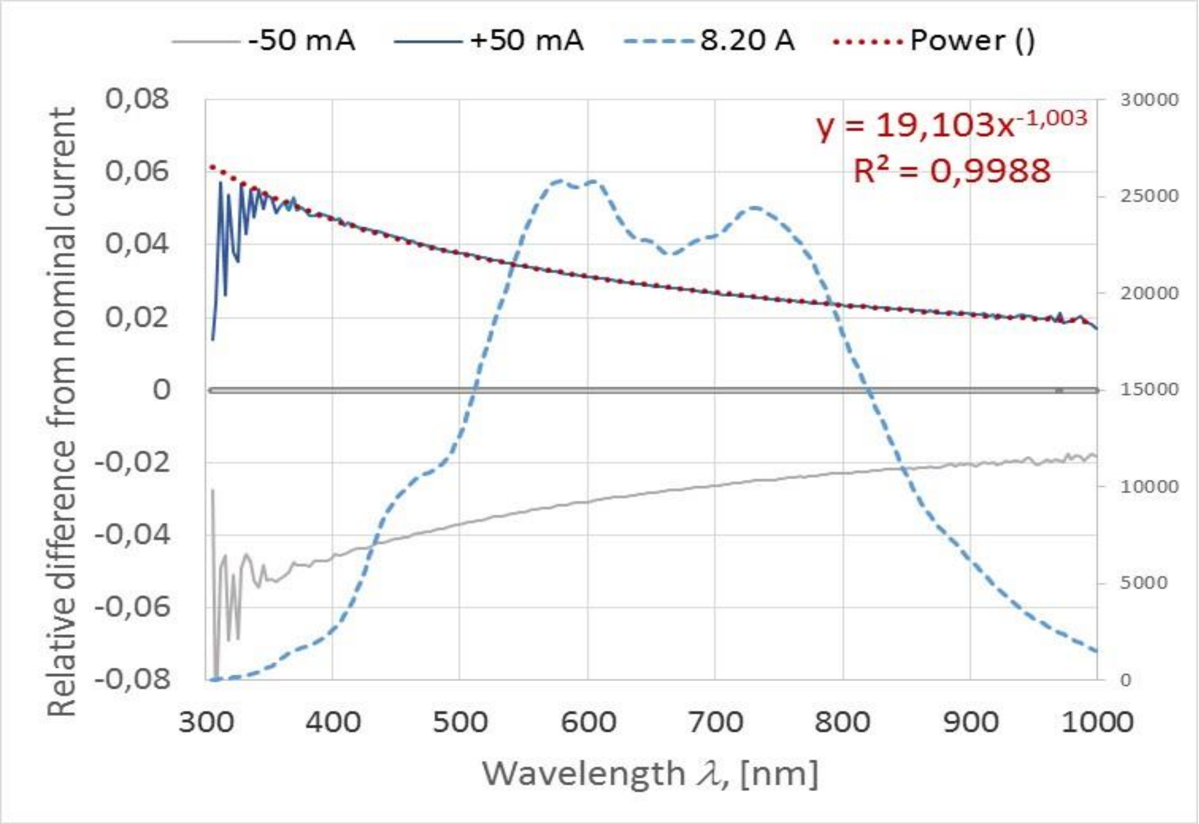
Monitoring the FEL light source with a trap detector

Relative change of the photocurrent of a filter radiometer regularly monitoring the FEL during the inter-comparison from Oct. to Dec. 2016.



The effect of lamp current offset

Three spectra are measured, one with nominal current of 8.2 A and two with current deviating ±50 mA from nominal. Power function trendline is added.



Inversely proportional functions of wavelength

At 300 nm a 1 % change in lamp current leads to a 10 % change in irradiance.

From the previous slide the inversely proportional dependence of uncertainty of the lamp current as a function of wavelength is evident.

Lamp aging may show similar features, because one of major effects of aging is increase of resistance of the tungsten filament with working time.

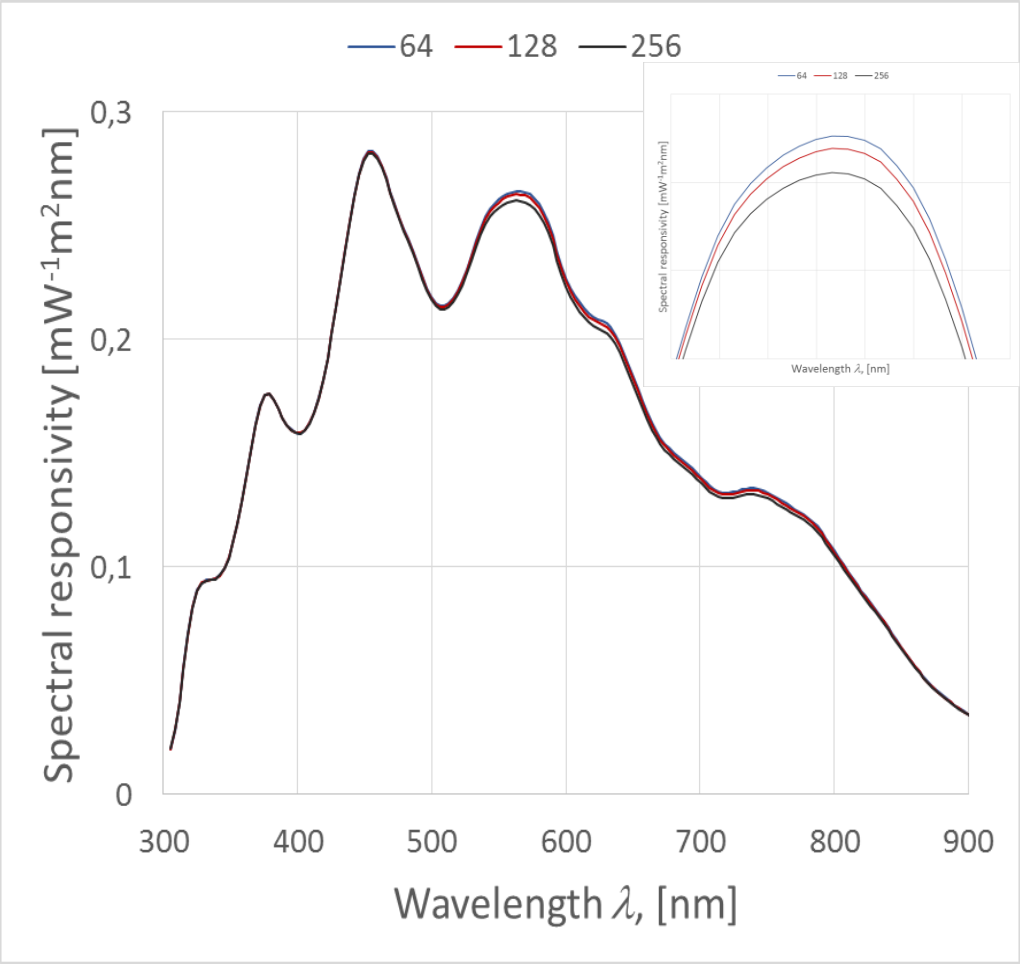
Thus, dependence on the wavelength likely will be of the same kind.

Non-linearity due to different integration times.

Responsivity spectra of a radiometer from data obtained with different integration times may vary several percent's.

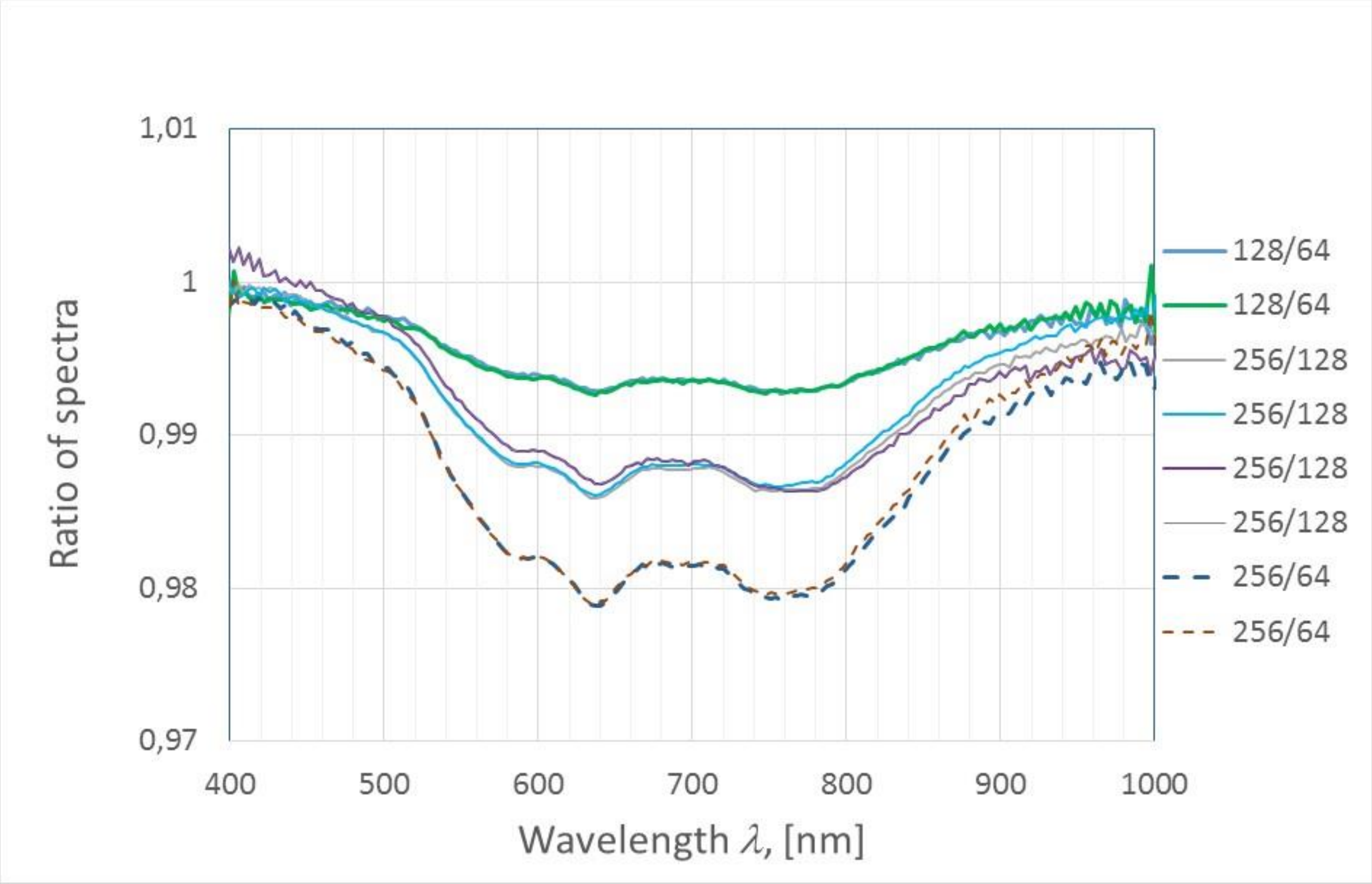
Nature of variation may be predictable or non-predictable.

Responsivity spectra of TriOS RAMSES vary in predictable way: the smaller the integration time the larger the particular spectrum, and the non-linearity effect is proportional to the integration time used.



Non-linearity effect of systematic nature

Ratio of spectra with integration times of 256 ms, 128 ms and 64 ms.



Non-linearity correction

At least two different spectra are needed for every corrected spectrum. Spectrum $S_{1,2}(\lambda)$ corrected for nonlinearity is calculated by using the following formula:

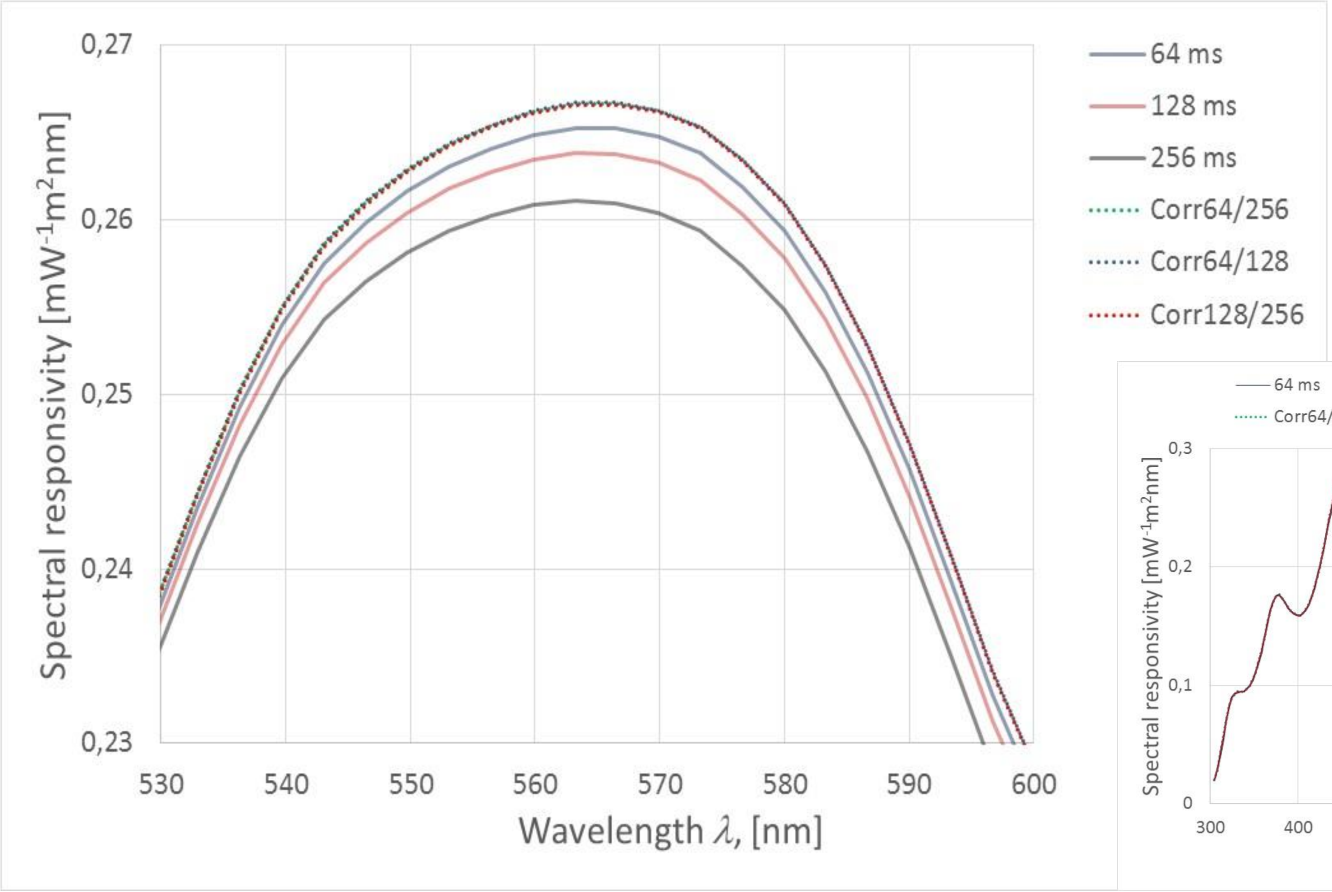
$$S_{1,2}(\lambda) = \left[1 - \left(\frac{S_2(\lambda)}{S_1(\lambda)} - 1\right)\left(\frac{1}{t_2/t_1 - 1}\right)\right] S_1(\lambda) .$$

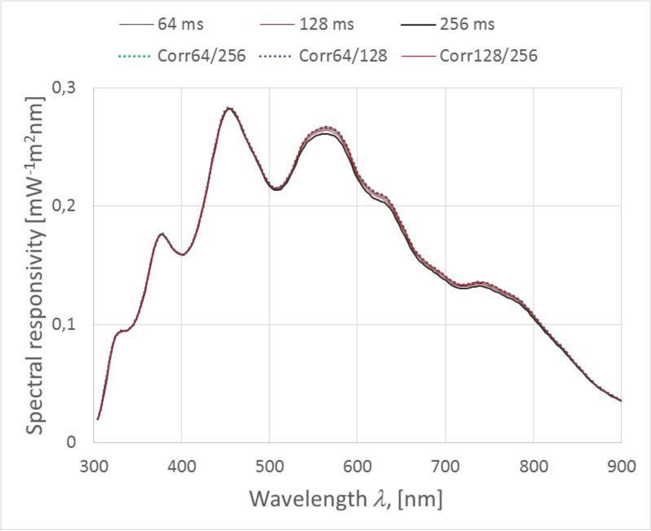
Here $S_1(\lambda)$ and $S_2(\lambda)$ are the initial spectra measured with integration times t_1 and t_2. Minimal ratio usually is t_2/t_1=2, but it may be also 4, 8, 16, etc.

For large ratios t_2/t_1 > 8 the spectrum $S_1(\lambda)$ is close to $S_{1,2}(\lambda)$, so that correction is usually not needed.

Spectra corrected for non-linearity

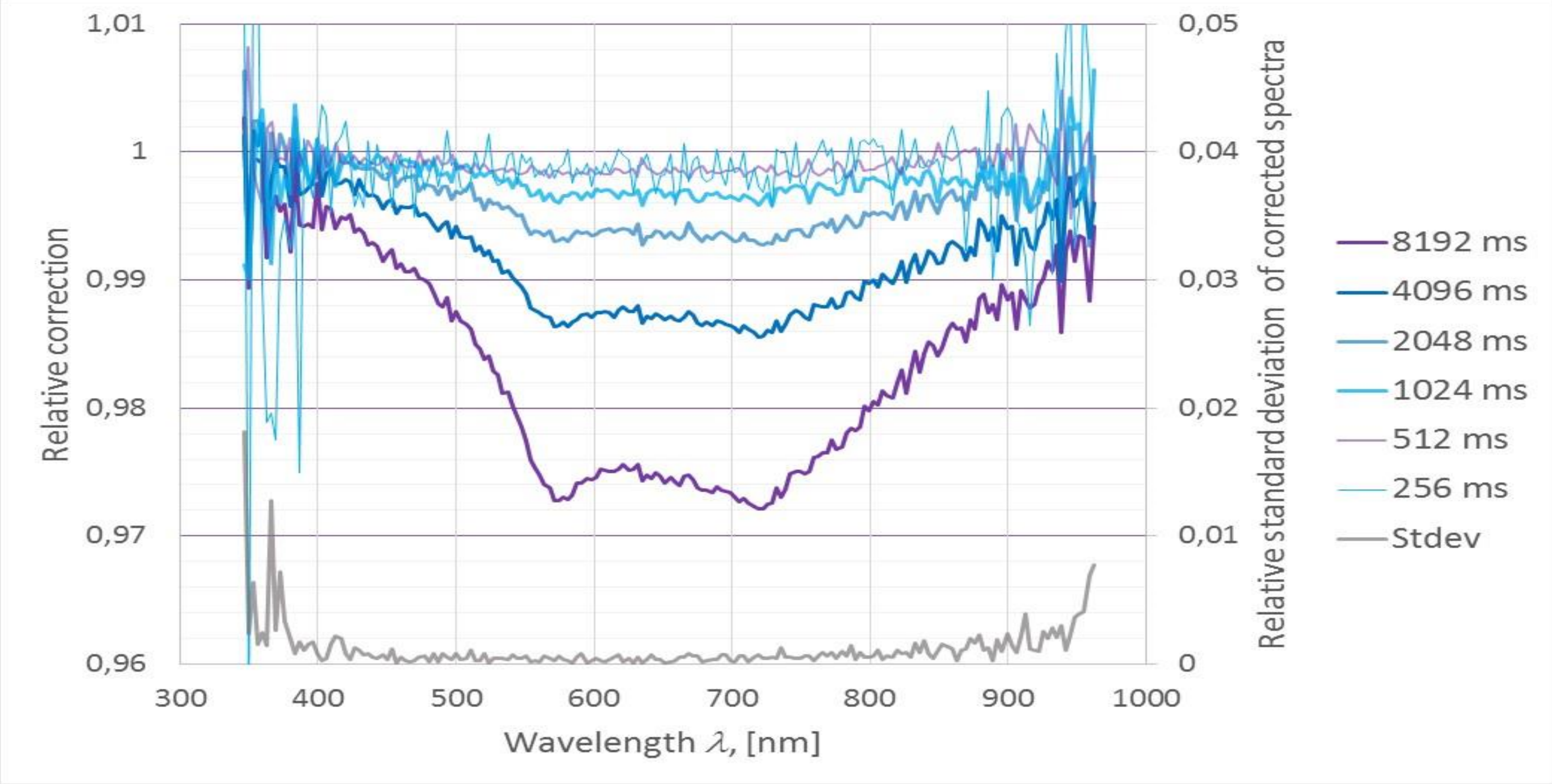
Measured and corrected spectra as a function of integration time.





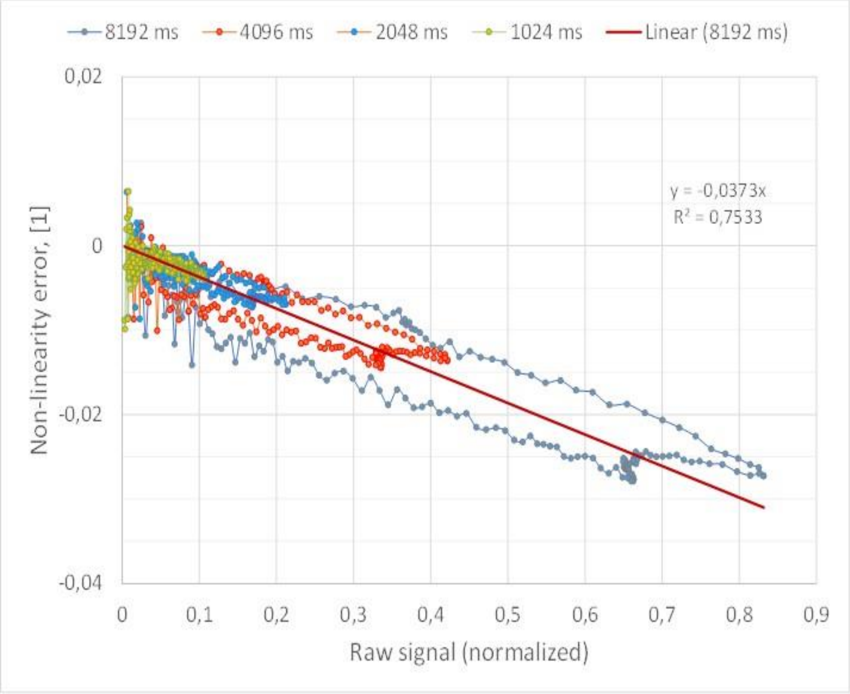
Effectiveness of non-linearity correction

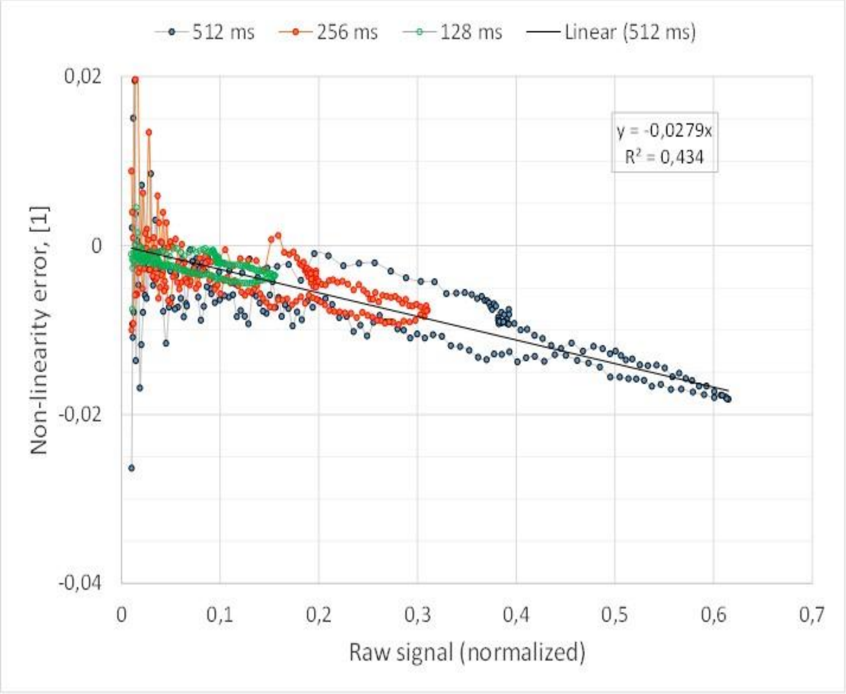
The correction formula is quite useful for certain types of radiometers (TriOS RAMSES, Satlantic HyperOCR).



Non-linearity correction

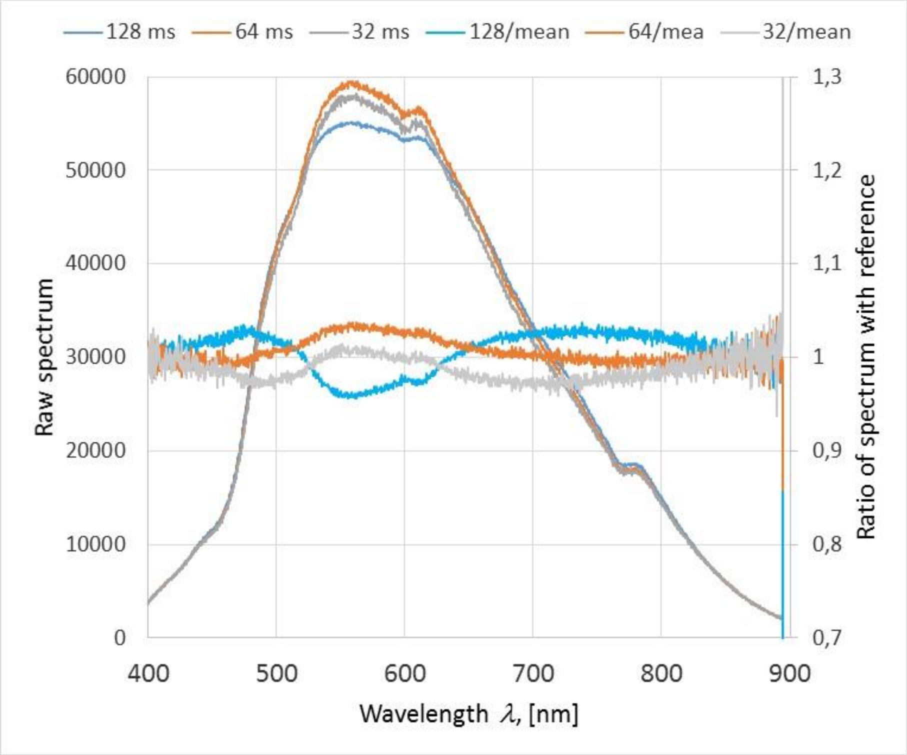
By using the two-spectra formula, the non-linearity effect due to different integration times can be corrected to 0,1 %. It is impossible by using average correction as a function of signal amplitude. Non-linearity error of TriOS RAMSES (left) and Satlantic HyperOCR (right) radiometers.

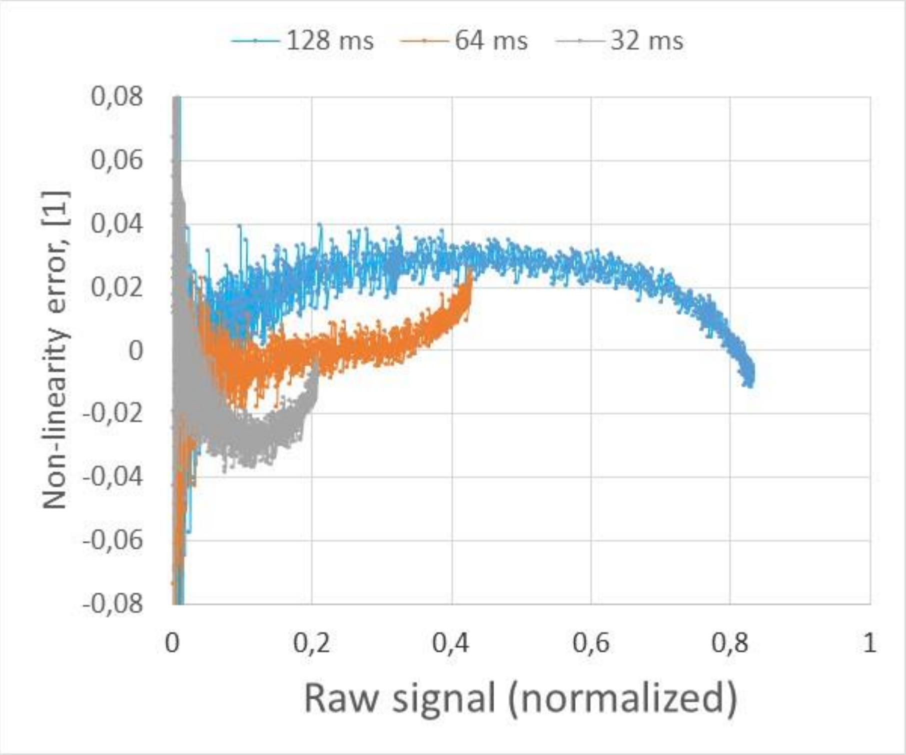




Non-linearity effect of non-predictable nature

Non-linearity error of the WISP-3 radiometer (downwelling radiance channel): constant source measured with different integration times. Non-linearity error against the averaged value of spectra.

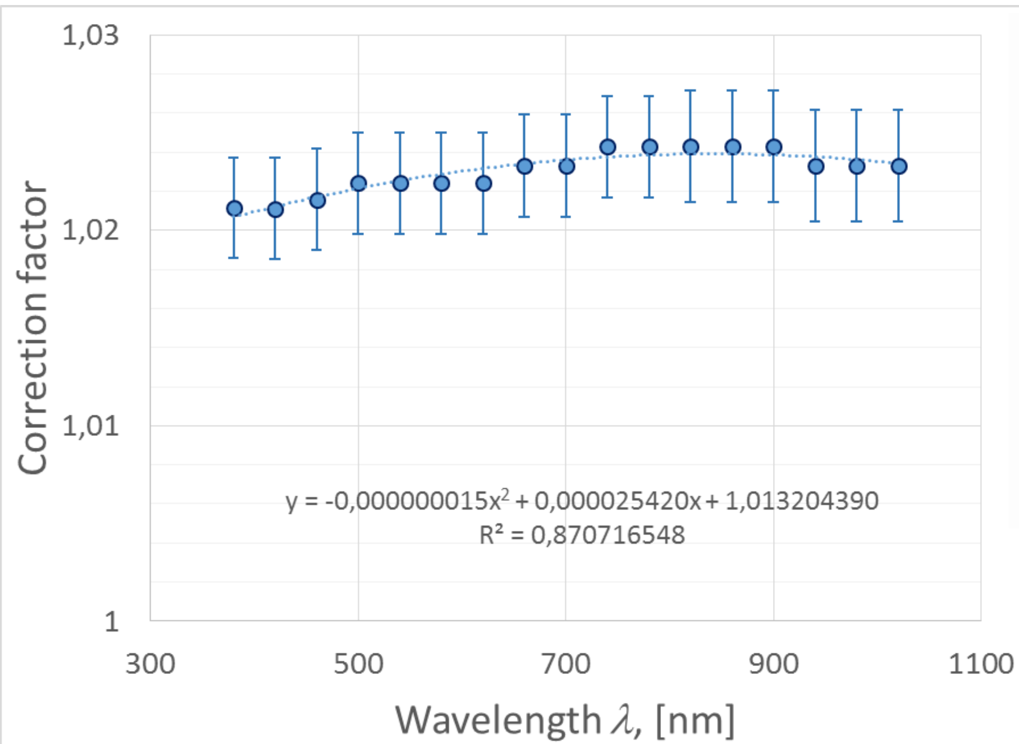


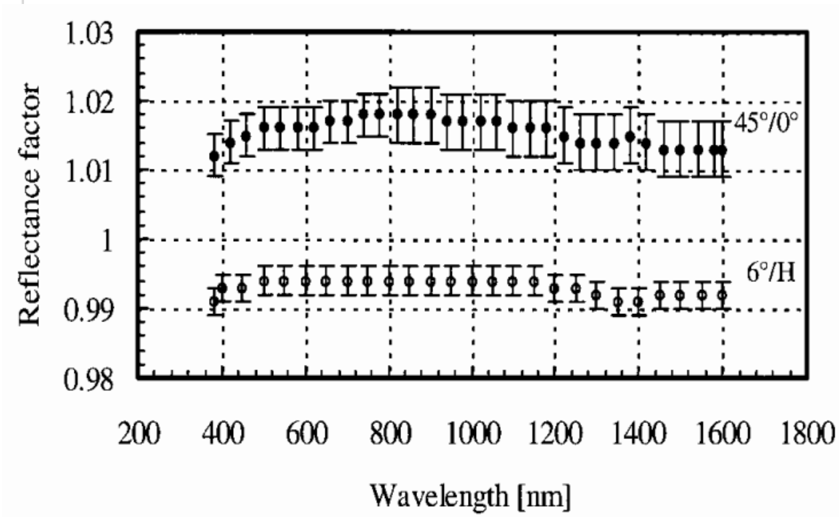


Reflectance difference of bidirectional and hemispherical geometries

Correction for directional-hemispherical spectral reflectance R(6°/H) specified in certificate to obtain bidirectional reflectance factor R(0°/45°).

After M.E. Nadal and P.Y. Barnes, 1999.

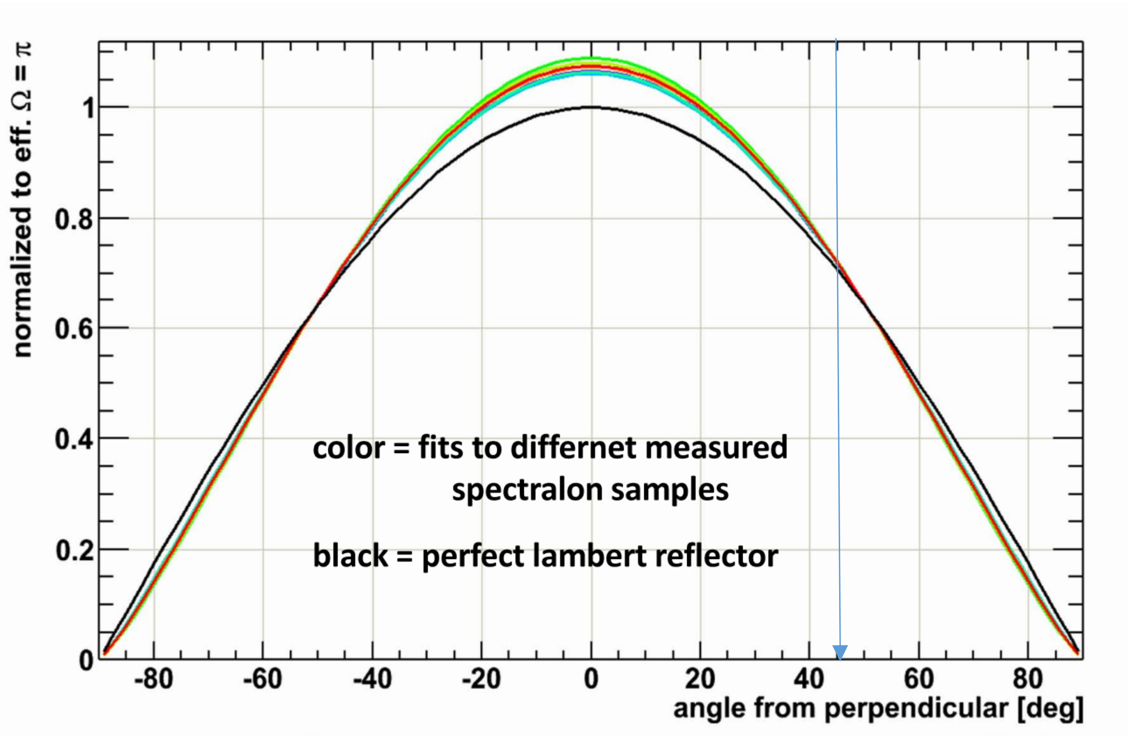


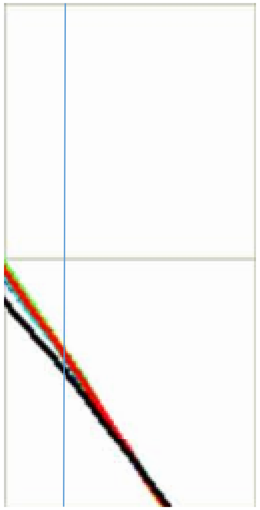


TARTU OBSERVATORY
space research centre

Perfect lambert reflector cannot be realized

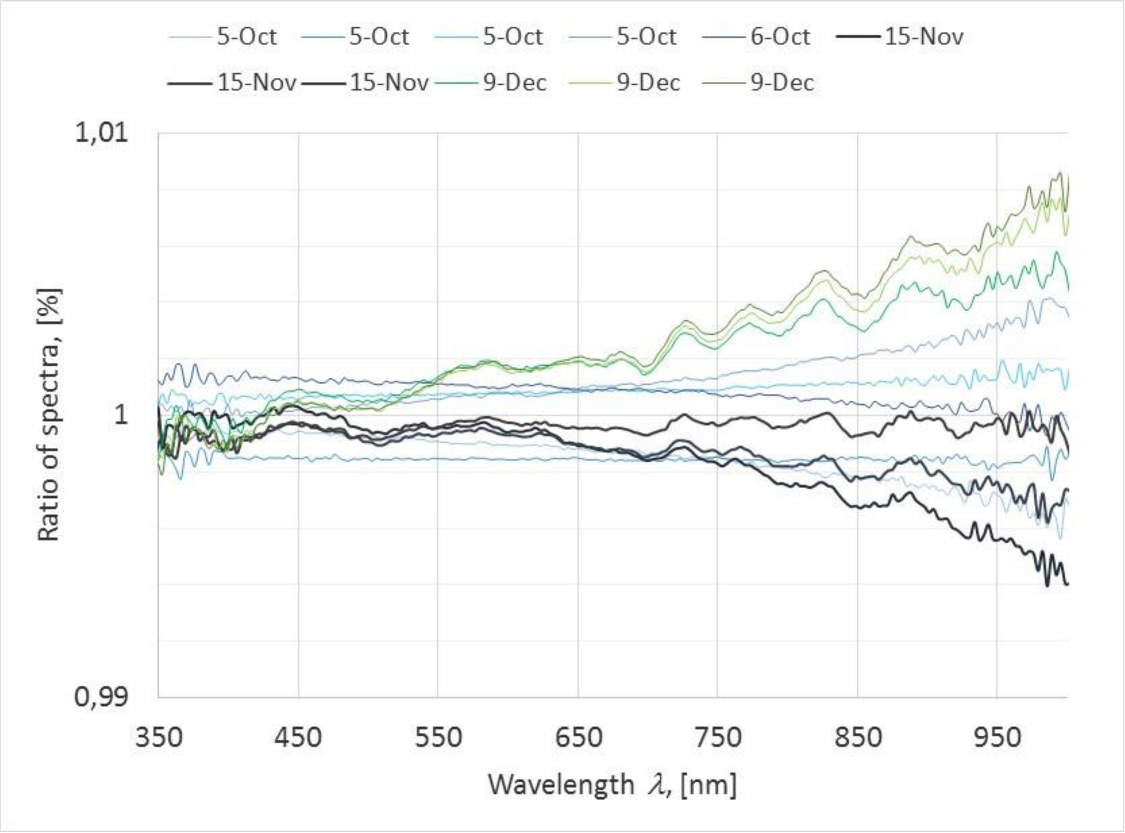
Difference of real samples from perfect lambert reflector.
After H. Kellermann, 2011.





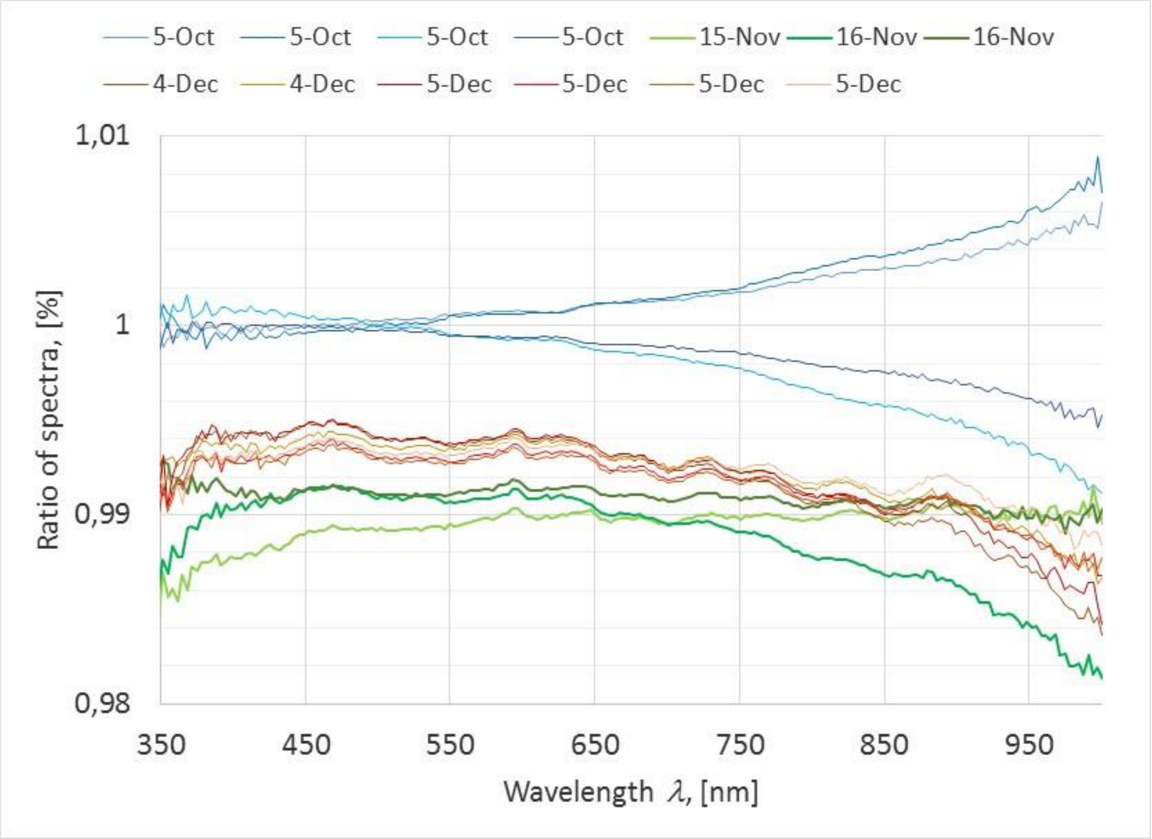
Alignment and temperature effects

Repeated alignment of TriOS Ramses ARC sensor. Variability due to instability of the sensor and due to temperature effects also may be involved.



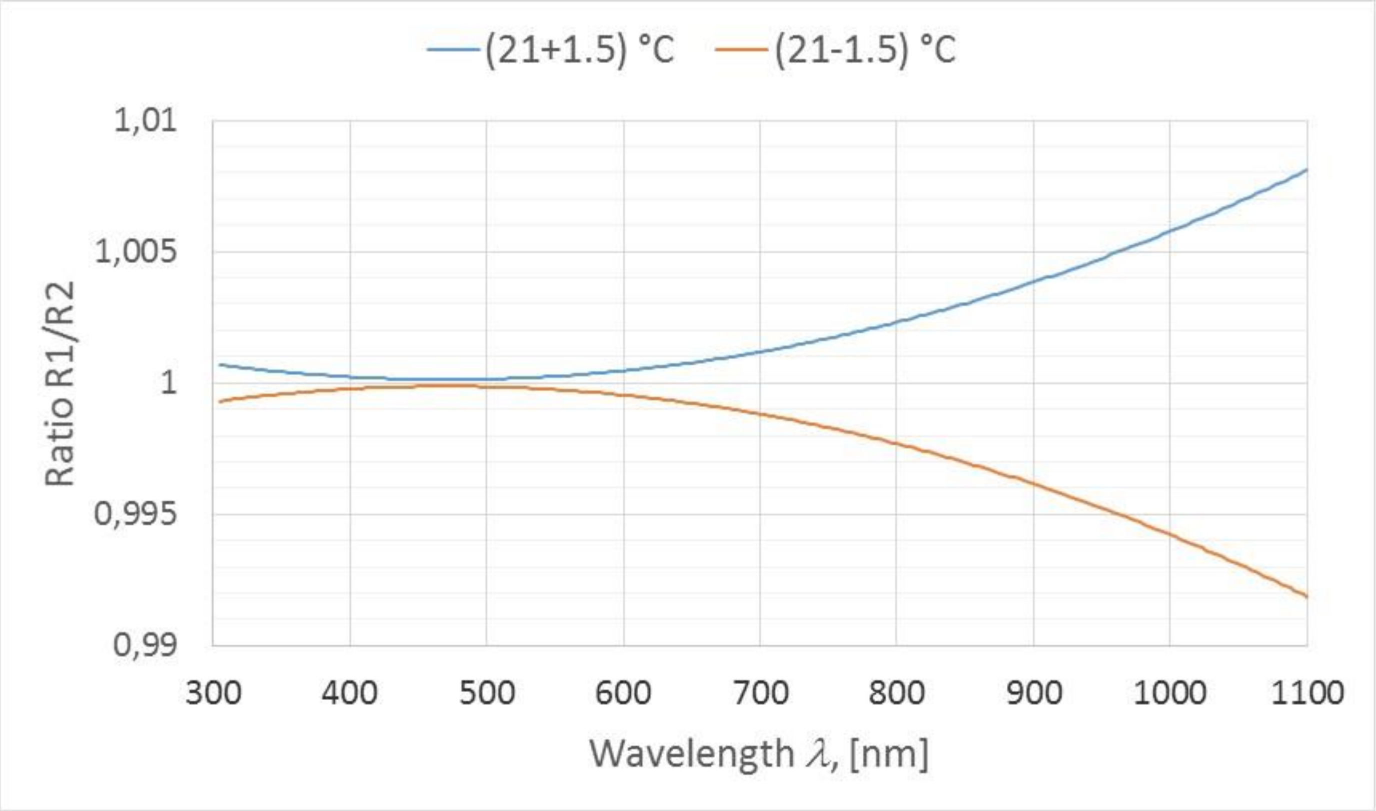
Alignment and temperature effects

Repeated alignment of TriOS Ramses ACC sensor. Variability due to instability of the sensor and due to temperature effects also is evident.

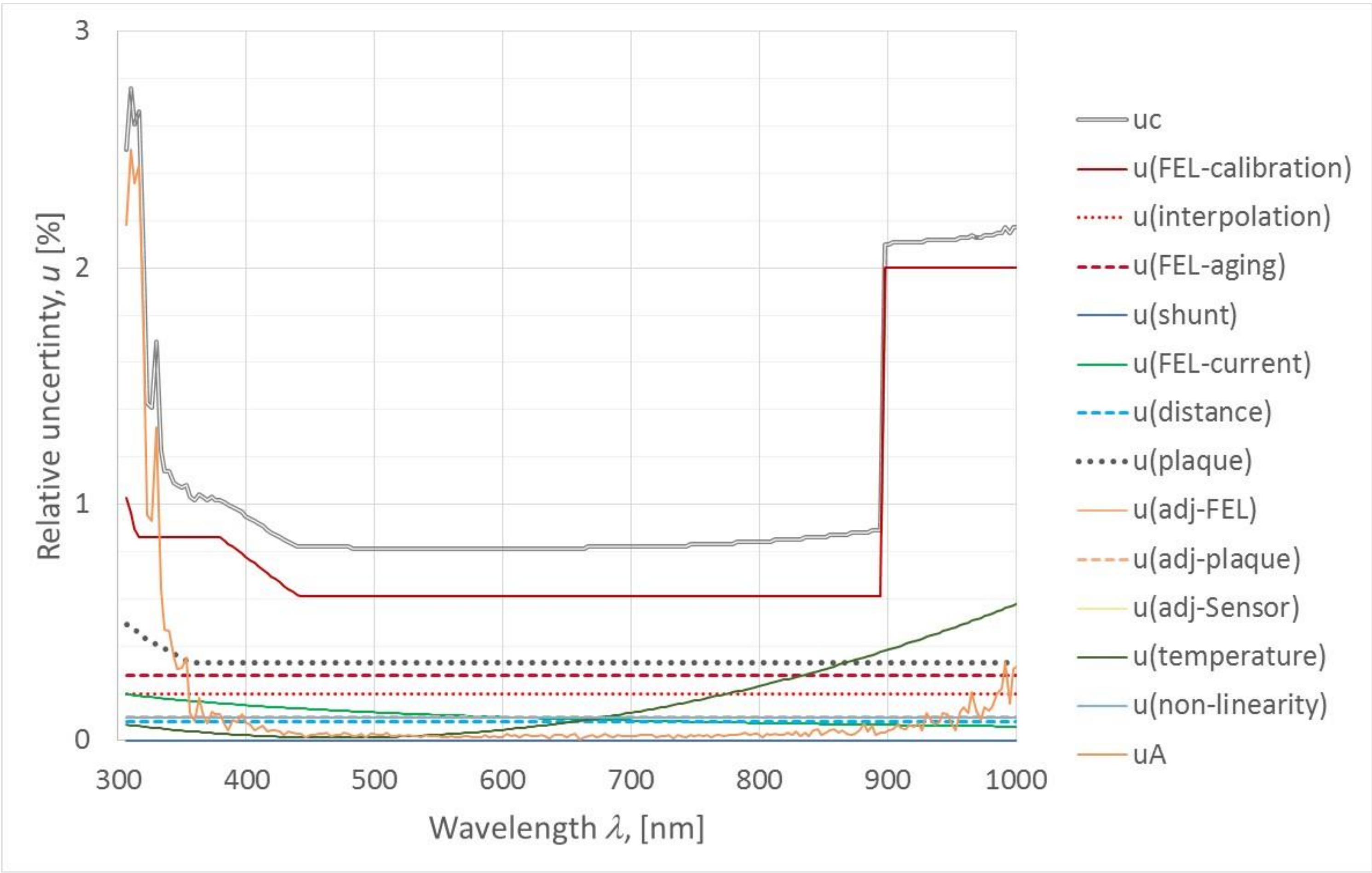


Modelled temperature effects

Modelled temperature effects for lab conditions (21±1.5) °C. Spectrum R1 assumed at 22.5 °C and 20.5 °C. Spectrum R2 assumed at 21 °C.



Relative standard uncertainty for calibration of radiance sensors



Comparison calibration of the field radiometers

Participants:

1. Tartu Observatory, Estonia, pilot lab
2. TriOS, Germany
3. JRC, EC
4. NPL, UK

Comparison instruments:

1. TriOS Ramses ARC VIS radiance radiometer
2. TriOS Ramses ACC-2 VIS irradiance radiometer

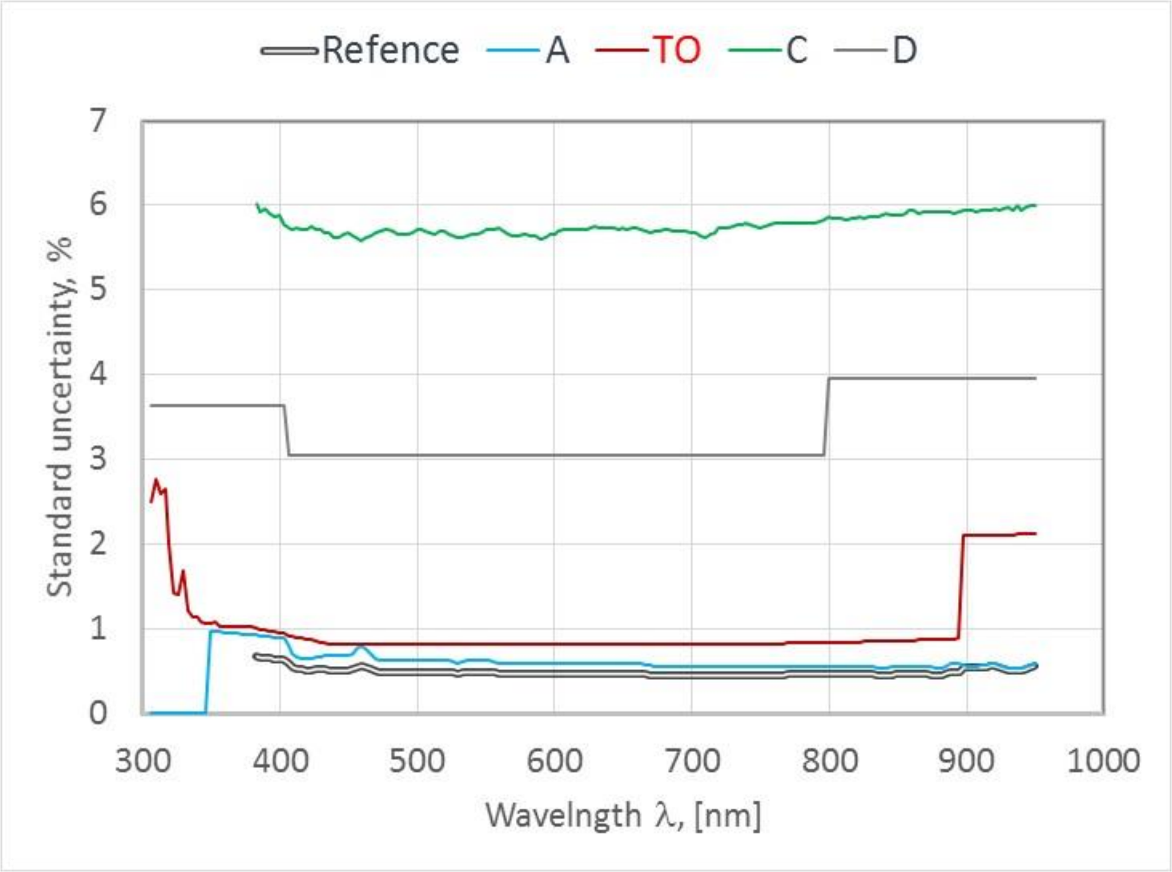
Comparison reference values:

The reference values were calculated as a weighted mean of the values of all participants (after M. G. Cox, 2002), as satisfactory agreement between participants was present.

TARTU OBSERVATORY
space research centre

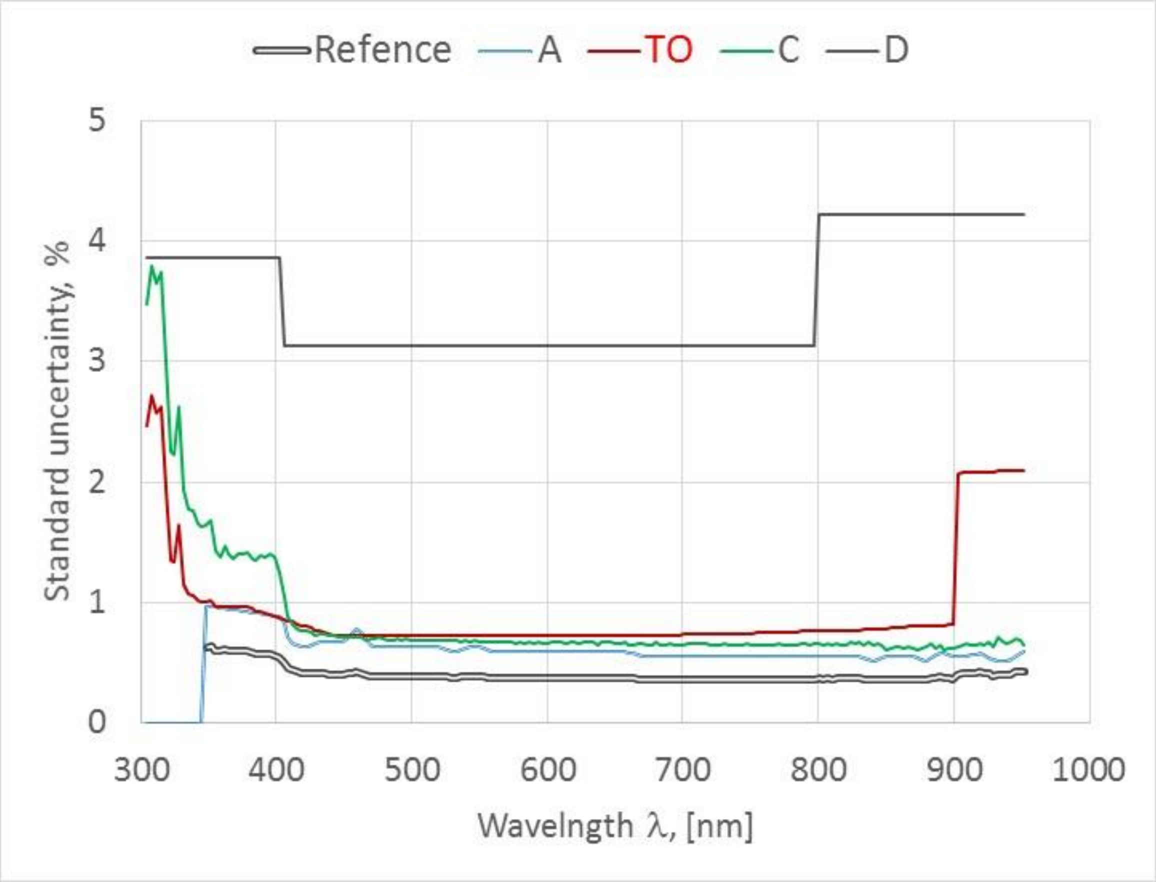
Uncertainty estimates

Relative standard uncertainties of participants for the radiance sensor.



Uncertainty estimates

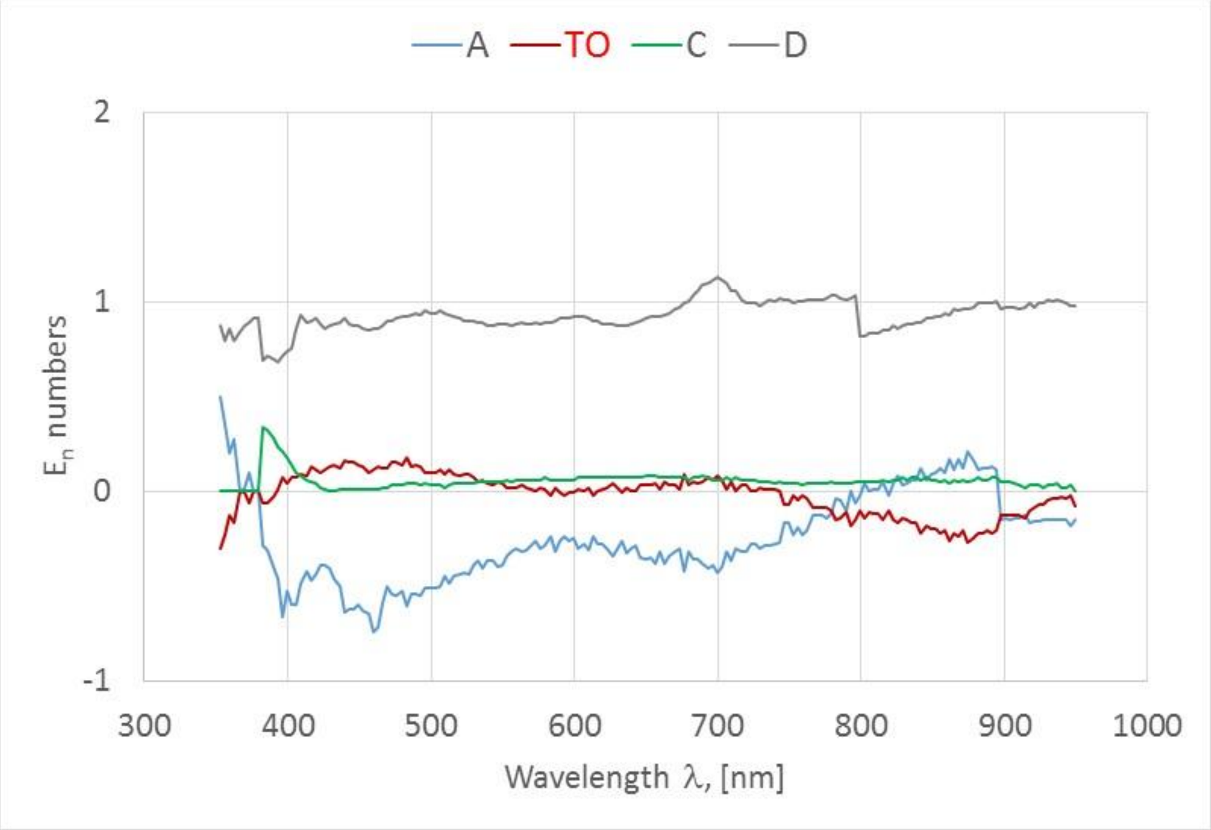
Relative standard uncertainties of participants for the irradiance sensor.



TARTU OBSERVATORY
space research centre

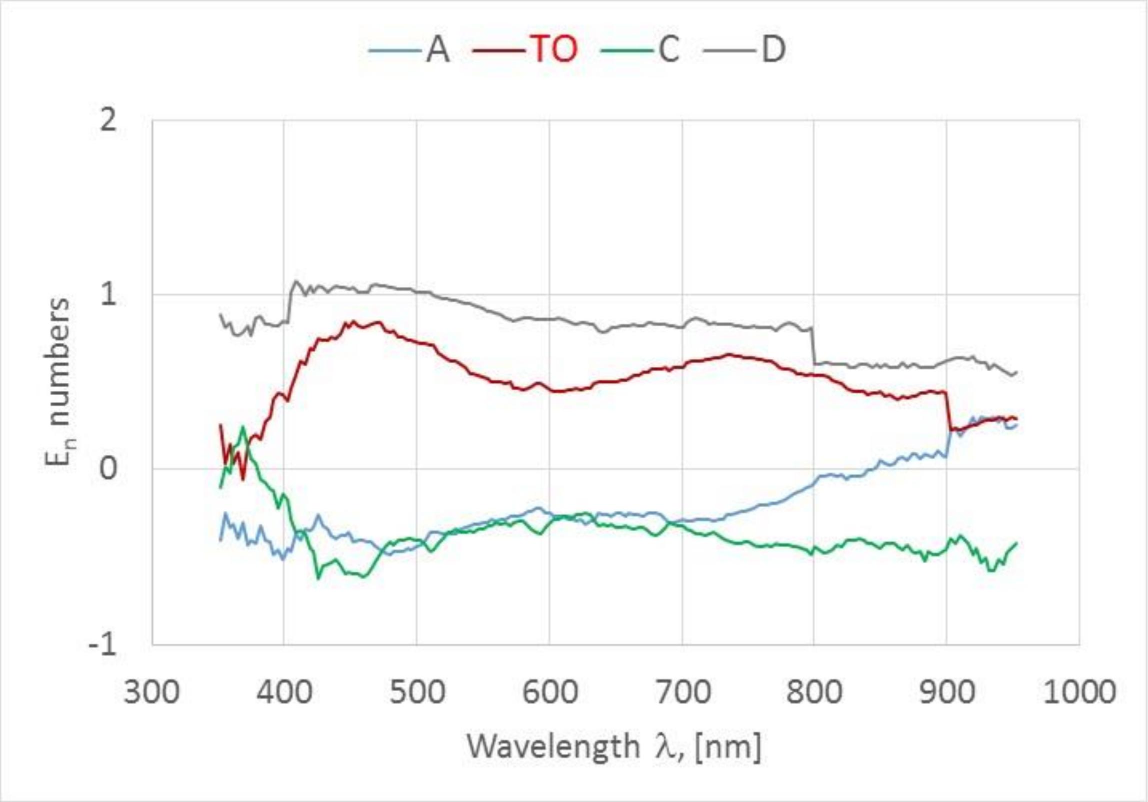
Comparison results as En numbers

Agreement with the reference value for the radiance sensor responsivity.
Agreement is considered satisfactory if $E_n < 1$, and unsatisfactory for $E_n > 1.5$.



Comparison results as En numbers

Agreement with the reference value for the irradiance sensor responsivity.
Agreement is considered satisfactory if $E_n < 1$, and unsatisfactory for $E_n > 1.5$.



Summary

Sources of uncertainty in radiometric calibration are considered in the order of decreasing importance.

- Calibration of lamp and aging; Calibration of plaque and aging
- Operation of lamps: lamp current
- Distance measurement and alignment: lamp – plaque – radiometer
- Corrections: linearity, ambient temperature, stray light

Radiometric calibration with standard uncertainty close to 1% is possible only if all significant biases are effectively corrected, and uncertainty sources carefully handled.

Inter-comparison measurement between four participants has shown satisfactory agreement confirming the small uncertainty stated by TO.