Calibration setup

General

During the calibration process NIST standard lamps (DXW-1000W, 120V) are used. The absolute optical output of the lamps is calibrated by Gigahertz-Optik GmbH.
Lamps are operated using a highly stabilized current source. Current is monitored continuously during measurement. Additionally the voltage directly at the clamps of the lamp is monitored. On both optical setups, for irradiance and radiance, one reference radiometer (RAMSES-ACC or RAMSES-ARC, respectively) is permanently fixed in the setup and operated simultaneously during the calibration process to monitor the optical output of the lamp. Calibration is performed in a dark lab (size: 3.5 m x 3.5 m, height: 4.5 m) which is painted with an highly absorbing black color to minimize reflectance.

All measurements, including the dark current matrix (for each integration time), lamp and ambient stray light are done performing (at least) 16 measurements and taking the mean value. This means, (12 (dark, 4 ms..8192 ms) + 1 (lamp) + 1 (ambient)) · 16 measurements = 224 spectra are performed and analyzed for calibration.

Irradiance

Irradiance sensors are calibrated in a vertical setup: A halogen lamp is positioned 50 cm above the radiometer. The reference radiometer is positioned rotated beside the other sensor in a way, that the cosine collector is also in a 50 cm distance, viewing at the same angle. On a second measurement, a shutter is positioned between the lamp and the sensor to obtain ambient stray light spectra.

Radiance

Radiance sensors are calibrated using a 10"x10" spectralon plate which is illuminated by a halogen lamp from a distance of 50 cm. Two radiance sensors (one for calibration, one for reference) are sampling the reflected light from the spectralon plate from two different sides. The sensor are positioned in a way that no shadow is produced on the reflectance plate. Again, for determining the ambient stray light, a shutter is placed between the lamp and reflectance plate.

General Data Processing

Data conversion and normalization

The binary data from the sensor are 16-bit unsigned integer data of the interval [0..65535].
They are divided by 65535 to get floating point data from the interval [0.0 .. 1.0].
These are called "raw data" in the following processing steps.

Offset subtraction

The background data and electronical offset are subtracted from the raw data. The background data is supplied together with the sensor in the file

BACK_SAM_xxxx.dat. The electronical offset is determined from blackened pixels at the end of the diode array.
The background data file either can contain one single data column B or alternatively two data columns B_0 and B_1. In the second case the background is calculated according to the equation

$$B = B_0 + t/t_0 \cdot B_1$$

where t is the integration time derived from the range setting (4 ms .. 8192 ms) and t_0 = 8192 ms is a normalisation factor.

Range scaling

Data are normalised to a range setting of t_0, i.e. data are scaled by a factor $k = t_0 / t$ (<range>)

Spectral calibration

The spectrum is divided by the sensitivity function of the sensor and data is converted to physical units (Power scale / quanta scale), either mW / (m^2 nm) respectively µmol / (s m^2 nm) for the irradiance sensors or mW / (sr m^2 nm) respectively µmol / (s sr m^2 nm) for the radiance sensors.

The sensitivity function is derived from measurements with a calibrated lamp and supplied together with the sensor in the file CAL_SAM_xxxx.dat

Summary for msda_xe data processing step 1..3

I (n)	n=1..255	16-bit unsigned integer data from the sensor
M (n)	n=1..255	Floation point raw data [0.0 .. 1.0] (exported Raw Data)
B (n)	n=0..255	Background data file (one data column, BACK_SAM_xxxx.dat by default)
$B_0(n)$, $B_1(n)$	n=0..255	alternatively: Background data file (two data columns, BACK_SAM_xxxx.dat by default)
S (n)	n=0..255	Sensitivity data file (CAL_SAM_xxxx.dat by default)
t		Integration time $t = 2^{range+1}$ ms, range= M(0) i.e. [1..12] <=> t = 4 ms .. 8192 ms
t_0		8192 ms

1. Data conversion and normalisation

$$M(n) := I(n) / 65535$$

2. Background subtraction

$C(n) := M(n) - B(n)$ n=1..255, if 2 column background data are available:
$B = B_0 + t/t_0 \cdot B_1$

Determination of offset from dark pixels
Offset = Mean(C(i), $i=n_1..n_2$),
n_1 and n_2 are device properties.

Shift of the spectrum
$D(n) := C(n) - \text{Offset}$ n=1..255

3. Normalization for the integration time

$E(n) := D(n) \cdot t_0 / t$ n=1..255

4. Sensitivity calibration

$F(n) := E(n) / S(n)$ n=1..255

where F(n) are spectral data calibrated in physical units

Up to this point all data processing have been performed for each sensor element of the detector array.

5. Wavelength calibration

The wavelength is calibrated by Carl Zeiss Jena GmbH during the manufacturing process of the spectrograph. It is given as a function of pixel number N=1 to 256, respectively. The function λ (N) is fitted by polynomials of 3rd order:

$$\lambda(N) = C0s + C1s \cdot N + C2s \cdot N^2 + C3s \cdot N^3$$