MERIS & OLCI Radiometric Calibration

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Workshop on Radiometric Calibration for European Optical Missions

Disclaimer
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Overview

• Instruments Overview
• Radiometric Calibration methods
• Spectral Calibration methods
• Radiometric Calibration Results
• Spectral Calibration Results
• Additional slides: OLCI Yaw Manoeuvres (time permitting)
Instrument overview

• Instrument principle
• CCDs outline
• Smearing signal: a bit more
• Radiometric Equation
• OLCI specificities

Radiometric Calibration methods
Spectral Calibration methods
Radiometric Calibration Results
Spectral Calibration Results
MERIS & OLCI instrument principle

- Push-broom imaging spectrometer, 5 fan-arranged cameras
- Radiometric calibration based on on-board diffuser(s)
- Spectral calibration using dedicated on-board diffuser
- Radiometric calibration outside EO observation window
• Imaging area 740 (spatial) by 520 (spectral) pixels
• 3 groups of dark witness samples: 5 masked on each side + 4 virtual
• (up to 45) programmable microchannels built by addition of elementary lines in the shift register
• ~42.7 ms exposure, transfer to storage zone in ~1.3 ms, without shutter → smearing
• A virtual microchannel measures spectrally integrated smear signal
• Further: channels built by digital addition of µchannels
Smear signal is due to the residual exposure to light during charge transfer from the image zone to the storage zone of the CCD:

Each actual channel is corrected by a weighted average of smear channel values at $t_1$ and $t_2$, weights being derived according to channel wavelength$^1$:

$$Sm\left( b, \frac{t_1 + t_2}{2} \right) = \frac{X_{sm}(t_1) \cdot (\lambda_b - 390) + X_{sm}(t_2) \cdot (1040 - \lambda_b)}{1040 - 390}$$

$^1$: ignoring scaling by channels' widths and electronic gains for the sake of demonstration
\[ X_{b,k,m,f} = \text{NonLin}_{b,m} \left[ g(T^\text{VEU}_f) \left[ A_{b,k,m} \left( L_{b,k,m,f} + G_{b,k,m} (L_{*,**},f) \right) + \text{Sm}_{b,k,m,f} (L_{b,k,m,*}) \right] + g_c (T^\text{CCD}_f) C^0_{b,k,m} \right]. \]

- \( X_{b,k,m,f} \) is the MERIS raw sample,
- \( \text{NonLin}_{b,m} \) is a non-linear function
- \( T^\text{VEU}_f \) is the temperature of the MERIS amplifiers (VEUs);
- \( T^\text{CCD}_f \) is the temperature of the MERIS detectors (CCDs)
- \( g(T) \) and \( g_c(T) \) are (dimensionless) temperature correction functions;
- \( A_{b,k,m} \) the "absolute radiometric gain"
- \( L_{b,k,m,f} \) the spectral radiance distribution in front of MERIS;
- \( \text{Sm}_{b,k,m,f} \) the smear signal, due to continuous sensing of light by MERIS;
- \( C^0_{b,k,m} \) the calibrated dark signal (possibly including an on-board compensation), dependent on band and gain settings;
- \( G_{b,k,m,f} \) a linear operator representing the stray light contribution to the signal
OLCI specificities

+ 12 degrees westward tilt to minimize Sun glint and increase swath to 1250km
+ Number of bands increased to 21 (full CCD spectral range used)
+ Calibration modes downloaded in micro-channels (up to 45), specific modes pre-programmed: RC with nominal channels with D1 & D2 (=ref.), spectral with using doped (Erbium) or white (Fraunhofer) diffusers, EO with specific channels (O2-A & Fraunhofer), along-orbit Dark measurements
+ Technological improvements...
+ Full EO mission acquired in FR (300m), RR L1 built from FR L0
Instrument overview

Radiometric Calibration methods

• Radiometric Approach
• Radiometric Processing
• Radiometric Calibration Key Inputs

Spectral Calibration methods

Radiometric Calibration Results

Spectral Calibration Results
Radiometric Approach

- Calibration modes provides instrument numerical counts $X_{\text{cal}}(\lambda,k)$ and $X_{\text{dark}}(\lambda,k)$
- Instrumental corrections (non-linearity, dark offset, smear) yields $X'_{\text{cal}}(\lambda,k)$
- Instrument Gain from $X'_{\text{cal}}(\lambda,k) = G(\lambda,k).L_{\text{cal}}(\lambda,k)$
- $L_{\text{cal}}$ computed from $E_0(\lambda)$, geometry and diffuser BRDF
  - Diffuser BRDF characterised on-ground, used at flight condition via a model
  - $E_0(\lambda)$, from a model + seasonal variation
  - Geometry from orbit/attitude and instrument pointing characterisation

- Space environment implies ageing of Diffuser and Optics
  - 2nd diffuser to monitor diffuser-1 BRDF ageing (~ every 3 months)
    => **Diffuser Aging model**
  - frequent calibration to monitor Instrument degradation (~ every 2 weeks)
    => **instrument degradation model**
Radiometric Processing

Gain computations

Sun Irradiance model

Instrument spectral model

In band irradiances, wavelengths

diffuser BRDF model

Gain computation

G(t)

Sun-View geometry

Calibration radiance

Level 1b processing

observation counts (corrected)

reference gains

degradation model

Calibration

Radiances

Gain modelling

{G(t)}

diffuser ageing model

instrument degradation computation

reference gains

degradation model
Radiometric Calibration Key Inputs

On-ground characterisation of diffuser (+model) 
(here MERIS D1 @ 410nm)

Extra terrestrial solar spectrum (Thuillier et al.)
In-band irradiance computed per pixel with on-board derived instrument Spectral Model
Instruments Overview

Radiometric Calibration methods

Spectral Calibration methods

• 3 kinds, with specific channels settings:
  a) Spectral Features of Erbium doped diffuser
  b) Solar Fraunhofer Lines on white diffuser or Earth target
  c) O2-A absorption line on Earth target

• General methodology: matching data with reference spectra.

Radiometric Calibration Results

Spectral Calibration Results
Spectral Calibration channel settings

OLCI case: the most complete.

MERIS case: a subset
- 2 Erbium lines (408 & 520)
- 6 Fraunhofer lines (no 409, 430, 1000)
- 1 O2 line (761)
- Fraunhofer and O2 less frequent (manual campaigns)
Spectral calibration overview

- Erbium spectrum with (simulated) OLCI samples
- Fraunhofer lines with OLCI/MERIS single-sample SRFs
- O2-A line with OLCI/MERIS single-sample SRFs
Instruments Overview
Radiometric Calibration methods
Spectral Calibration methods

Radiometric Calibration Results
• Counts and gains
• Diffuser ageing
• Instrument evolution

Spectral Calibration Results
Counts & Gains

**MERIS**

**OLCI**
**Diffuser Ageing**

**MERIS**

- Smoothly decreasing with wavelength
- A bit more than 2% after 10 years (412nm)

**OLCI**

- Same spectral behaviour
- Less than 0.2% after 1.4 year (at 412nm) → consistent with MERIS
- Larger uncertainty as the two diffusers’ BRDF differ more than for MERIS
Instrument Evolution: MERIS

- Maximum degradation < 5% after 10 years in space
- Strong dependency with Sun azimuth due to BRDF model limitations
- Long-term time series allows to go through
- Spectral behaviour sometimes unexpected (e.g. higher at 443 than 412)
Instrument Evolution: OLCI (1/2)

- Maximum *evolution* within \([-2,+2]\)% after 1.4 year in space
- No dependency with Sun Azimuth thanks to in-flight BRDF model (derived from Yaw Manoeuvres)
- Unexpected *sensitivity increase*
- Complex spectral behaviour, strongly camera dependent
- First 1.5 month unusable due to wrong Navigation/attitude
Instrument Evolution: OLCI (2/2)

Total evolution so far (top, from model over reliable time window) fairly consistent between cameras with exceptions: camera 1 in the very blue (400 & 412 nm) & Camera 5 in ref and NIR (≥ 620 nm)

Spectral shape similar to that of inverse filter (a.k.a. correcting filter, bottom), known to outgas slowly...

![Graph showing instrument evolution between 20160425 and 20170722]
Instruments Overview
Radiometric Calibration methods
Spectral Calibration methods
Radiometric Calibration Results
Spectral Calibration Results
• Measurement examples
• Cross-FOV variability
• Temporal stability
Spectral calibration results: OLCI measurement examples

Result of the **Fraunhofer calibration** (green line) and the **Erbium calibration** (blue line) for the 409nm (left), 520nm (middle) and 800nm (right) spectral features. The shaded area is the **uncertainty of the Fraunhofer calibration**, the red line is the **pre-flight data**. The upper line is for module 1 the lower line for module 4.
Summary of Fraunhofer results: cross-FOV variability

- very similar between MERIS & OLCI
- Very low spectral dependency of x-FOV variation (for a given camera)
- About 1 nm within a camera
- Up to 1.5 over the whole FOV
- Slight inter-camera variation of mean spectral slope
Spectral Temporal Stability: MERIS

- < 0.2 nm over 10 years, decreasing drift rate
- No measurable spectral dependence (apparent dependence for C4 not fully reliable as strongly influenced by 1st measurement done under approximately known geometric conditions)
Spectral Calibration

Time stability

- < ~0.15 nm over 16 months, decreasing drift rate
- No measurable spectral dependence
- Similar to MERIS, a bit faster, a bit higher
OLCI Spectral Calibration absolute results: Comparison with pre-flight

![Graph showing deviation from nominal linear vs. nominal wavelength and CCD row number for different wavelengths.]

- Deviation from nominal linear [nm]
- Nominal wavelength [nm]
- CCD row number

Legend:
- preflight col 370
- preflight col 5
- preflight col 736
- erbium col 370
- erbium col 5
- erbium col 736
- fraunhofer col 370
- fraunhofer col 5
- fraunhofer col 736
Thanks for your attention
OLCI Yaw Manoeuvres an in-flight BRDF model

Yaw manoeuvres: a way toward an in-flight BRDF model:

• OLCI Gain temporal stability when using on-ground BRDF model: correlation with Sun Azimuth Angle (SAA)

• Yaw Manoeuvres: a way to sample the SAA yearly cycle within a day and get rid of instrument evolution

• In-flight BRDF model, training and validation data, validation methodology

• Results
Radiometric gains, spatial & homogeneity and temporal stability

Gain Coefficients for band Oa1 (top) and Oa21 (bottom), all diffuser 1 radiometric calibrations so far (~13 months of data).
Radiometric gains ratios: temporal stability

400 nm:
Large temporal evolution (expected)
Unexpected spatial structures

1020 nm:
Small temporal evolution (expected)
Unexpected spatial structures more visible

Gain Coefficients ratios for band Oa1 (top) and Oa21 (bottom), all diffuser 1 radiometric calibrations so far (~13 months of data), ref. 07/12/2016.
Spatial structures correlated with diffuser illumination geometry: Sun azimuth angle’s yearly cycle.

Data from 01/03/2016 to 22/03/2017

**Sun angles during radiometric calibrations**

**SAA in diffuser frame (degrees)**

- 69
- 68
- 67
- 66
- 65
- 64
- 63

**SZA in diffuser frame (degrees)**

- 40
- 35
- 30
- 25
- 20

**Acquisition geometries**

**Day of Year**

**Sun azimuth angle during radiometric calibrations**

- 20
- 15
- 10
- 5
- 0

**Day of Year**

- 350
- 300
- 250
- 200
- 150
- 100
- 50
- 0

Sun azimuth yearly cycle with available calibrations
Radiometric stability: dependency with illumination geometry

Two types of variability:

- One is roughly “white”, correlated with Sun azimuth: likely BRDF model residual error
- The second is band and camera dependent: instrument evolution

\[
\frac{G(t,b)}{G(t_{\text{ref}},b)}
\]

100% correlated with SAA
From 17/11/2016 to 07/12/2016: **Yaw Manoeuvres**

**Acquisition geometries**

**Day of Year**

Sun azimuth yearly cycle with available calibrations
Yaw Manoeuvres: SAA variations at fixed time: get rid of instrument evolution

\[ \frac{G(t,b)}{G(t_{\text{ref}},b)} \]

Only one type of variability: roughly “white”, correlated with SAA, likely BRDF model residual error

\[ |t-t_{\text{ref}}| = 2 \text{ weeks} \]
• **Goal:** provide a updated BRDF model that do not show SAA dependency

• **Means:** use *in-flight data* (Yaw Manoeuvres) to best sample geometry space and *On-Ground Characterisation as absolute reference*

• **Validation:** updated BRDF model should allow to *reproduce instrument evolution* as measured at equal SAA, *while not modifying significantly the gain at reference geometry*
YM & in-flight BRDF model: validation methodology
YM & in-flight BRDF model: validation & reference data

**Reference dataset** is 6 YM calibrations, from which **model is derived**

**Validation dataset** is 6 calibration with (almost) YM SAAs but various $\Delta t$ from YM day: measures of instrument evolution wrt YM day

$\Delta SAA$ is respect to $SAA_{ref}=-30.87$, closest to central CHAR SAA

$\delta SAA$ is respect to YM counterpart

<table>
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<th>$\Delta SAA$</th>
<th>$\delta SAA$</th>
<th>$\Delta t$</th>
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<td>0.09</td>
<td>-177.2</td>
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<tr>
<td>5.6</td>
<td>-0.02</td>
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</table>
YM & in-flight BRDF model results

After several attempts, one model retained:

Criterion 1: Impact on reference gain: within 0.1%

AC profile for all bands

AC averages vs $\lambda$ for all cameras
YM & in-flight BRDF model results

Criterion 2: Ability to reproduce equal-SAA evolution (Oa1 & Oa5)

Equal-SAA

Updated Model with single reference

OA1

OA5
YM & in-flight BRDF model results

Criterion 2: Ability to reproduce equal-SAA evolution (Oa9 & Oa13)

Equal-SAA

Updated Model with single reference

Instrument evolution at equal SAA, Test Set, band Oa9

Instrument evolution wrt to ref. orbit, UPDATED Test Set, band Oa9

OA9

OA13
YM & in-flight BRDF model results

Criterion 2: Ability to reproduce equal-SAA evolution (Oa17 & Oa21)

Equal-SAA

Updated Model with single reference

Instrument evolution at equal SAA, Test Set, band OA17

Instrument evolution wrt to ref. orbit, UPDATED Test Set, band OA17

OA17

OA21
YM & BRDF model: average evolution & SAA dependency: 1) NIR-normalization

As SAA dependency is mostly white, and NIR more stable

- Use modified definition of evolution:

\[
\frac{G(t,b)}{G(t_{\text{ref}},b)} \rightarrow \left( \frac{G(t,b)}{G(t,b_{\text{ref}})} \right) / \left( \frac{G(t_{\text{ref}},b)}{G(t_{\text{ref}},b_{\text{ref}})} \right)
\]

![Graphs showing relative gain evolution with time for Camera 1 and Camera 5 with and without NIR normalization.](image-url)
YM & BRDF model: average evolution & SAA dependency: 2) in-flight BRDF model

Bad geometry due to Star Trackers SW issue

BRDF correction

Modelling period  Validation

→ First 2 months of mission not usable for absolute calibration
NIR normalization can however provide reliable evolution over this period
YM & BRDF model: allows to model Radiometric Evolution, performance?

Within 0.2%

← Data/model, including validation calibrations (averages and RMS), all bands, for each camera

Data/model for band 4 vs. pixel and time: the outlier is not the most recent

Model performance: model/data, band 4
YM & in-flight BRDF model: Conclusion

The in-flight BRDF model:

• Does not significantly modify the reference gain: traceability to ground characterization preserved

• Allows to well reproduce equal-SAA evolution, at the cost of additional noise

• Allows to correctly model instrument evolution so it can be accounted for in EO processing
BDRF model (ground version) sensitive to Sun azimuth

Characterization and in-flight illumination conditions

Diffuser BRDF modelling residuals

Model 1 vs Char: SZA 68.2, SAA -39.5
Model 1 vs Char: SZA 68, SAA -29.8
Model 1 vs Char: SZA 68.4, SAA -20.1
Model 1 vs Char: SZA 65, SAA -30.9
Model 1 vs Char: SZA 63.8, SAA -39.8
Model 1 vs Char: SZA 63.6, SAA -29.8
Model 1 vs Char: SZA 64, SAA -19.8