IOCCG Level 1 Workshop
MERIS
Instrument Calibration Methods and Results
1. Instrument overview
2. Radiometric equation
3. Radiometric calibration method
4. Radiometric calibration results
5. Instrument degradation
6. Diffuser aging
7. Spectral calibration methods
8. Spectral calibration results
9. Spectral stability
10. Instrument Spectral Model
Radiometric Calibration

- Radiometric Calibration based on in-flight measurements
- Relies on Spectralon diffuser characterization (pre-launch)
- Thuillier Solar Spectrum
- Uses the same radiometric model as in the L1 data processing

Calibration frequency
- Diffuser-1: 15 days
- Diffuser-2: 3 months
- Diffuser-Er: 3 months peak 3
- Diffuser-Er: 6 months peak 1
Radiometric Equation

\[ X_{b,k,m,f} = \text{NonLin}_{b,m} \left[ g(T_f^{\text{VEU}}) \left[ A_{b,k,m} \left( L_{b,k,m,f} + G_{b,k,m}(L_{*,*,*,f}) \right) + S_{b,k,m,f}(L_{b,k,m,*}) \right] + g_c(T_f^{\text{COD}})C_{b,k,m}^0 \right]. \]

- \( X_{b,k,m,f} \) is the MERIS raw sample.
- \( \text{NonLin}_{b,m} \) is a non-linear function.
- \( T_f^{\text{VEU}} \) is the amplification unit temperature.
- \( T_f^{\text{COD}} \) is the sensor temperature.
- \( g(T) \) and \( g_c(T) \) are temperature dependent gain terms.
- \( A_{b,k,m} \) is the "absolute radiometric gain".
- \( L_{b,k,m,f} \) is the spectral radiance distribution in front of MERIS.
- \( S_{b,k,m,f} \) is the smear signal, due to continuous sensing of light by MERIS.
- \( G_{b,k,m} \) is a linear process representing the stray light contribution to the signal. For a given sample, some stray light is expected from all the other simultaneous samples in the module, spread into the sample by specular (ghost image) or scattering processes.
- \( C_{b,k,m}^0 \) is the dark signal (corrected on board for temperature effects by the Offset Control Loop).
Space environment implies **ageing** of Diffuser and Optics
- 2nd diffuser to monitor diffuser BRDF ageing
- expected G variations with time (instrument ageing)
  - frequent update of G(t) OR instrument degradation model
  - Calibration measurements every 2 weeks (diffuser 1)
  - Diffuser Ageing monitoring every 3 months (diffuser 1 and diffuser 2 on successive orbits)

5 Imaging Spectrometers imply **in-FOV variations** of channels spectral response (inter & intra-cameras)
  - Instrument spectral model + on-orbit monitoring
  - Spectral calibrations every 3 months (diffuser 3 "spectral")
  - Spectral campaigns every year or so (specific bands)
Radiometric Calibration

**Principle**

- Calibration provides instrument numerical counts $X_{cal}(l,k)$
- Instrumental corrections (non-linearity, dark offset, smear) yields $X'_{cal}(l,k)$
- Instrument Gain such as $X'_{cal}(l,k) = G(l,k).L_{cal}(l,k)$
- $L_{cal}$ computed from $E_0(l)$, geometry and diffuser BRDF
  - Diffuser BRDF characterised on-ground
  - $E_0(l)$, from a model + seasonal variation
  - Geometry from orbitography and instrument pointing characterisation

- Space environment implies *ageing* of Diffuser and Optics
  - 2nd diffuser to monitor diffuser-1 BRDF ageing
    => Diffuser Aging model
  - frequent calibration to monitor Instrument degradation
    => instrument degradation model
Radiometric Calibration

Method

Sun Irradiance model

Instrument spectral model

In band irradiances, wavelengths

Gain computations

Sun-View geometry

diffuser BRDF model

Gain computation

Calibration radiance

Level 1b processing

Sun-View geometry

observation counts (corrected)

reference gains
degradation model

Radiances

Gain modelling

diffuser ageing model

instrument degradation computation

reference gains
degradation model

{G(t)}
**Diffuser BRDF model: ageing**

- Methodology: monitor D1 to D2 response ratio
- Seven years of data available: loss reaches 1.5% at 412 nm
- Analysis shows linear trend with time
- Steep decrease with wavelength

![Ageing Linear Fit results: BRDF loss in %/year](image1.png)

![Diffuser ageing wrt launch (all cameras)](image2.png)

![Reflectance variation (%) vs Wavelength [nm]](image3.png)
Diffuser BRDF characterisation

x 5 geom:

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Radiometric Calibration

Key Inputs

Comparison of in-band Extra terrestrial solar irradiance between Neckel & Labs and Thuillier et al.

On-ground characterisation of diffuser-1 @ 410nm

Details of the spectral model available in later slides
Radiometric Calibration Results

Radiometric Calibration raw digital counts

Corresponding Radiometric Gain Coefficients
Diffuser Model Error


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Characterisation Accuracy

Azimuth differences
22859 to 24059 = +4.2 deg
25259 to 24059 = -5.3 deg

The ratio of gains computed at extreme azimuth illumination direction to that computed at the nominal azimuth illumination direction, show the limitation of the diffuser model to resolve the exact diffuser's BRDF azimuth dependence.

A very similar signature is seen when comparing model error relative differences using the most similar azimuth angular spreads available from the diffuser characterisation data set. This indicates that the BRDF measured on-ground, better capture the actual BRDF of the diffuser than the model used.
At time of 2\textsuperscript{nd} re-processing, no significant degradation could be measured for NIR

\rightarrow \text{NIR was used as a normalisation to remove (most of) azimuth dependency}

**Modelling** (based on Barnes et al. for SeaWiFS) \[ G(t) = G(t_0) \cdot \left(1 - \beta \cdot (1 - \gamma \cdot e^{-\delta t})\right) \]
Instrument Degradation

Maximum degradation of < 4% after more than 7 years in space

Degradation Model based on the SeaWifs model (Barnes et al.)

\[ G(t) = G(t_0) \cdot \left( 1 - \beta \cdot (1 - \gamma \cdot e^{-\delta t}) \right) \]
Is NIR stability assumption valid after 7 years on-orbit?

Use quasi-constant azimuth to check model vs. raw degradation:

- IR degrades by > 0.5%
- Transfers to all bands through normalisation
Modelling without normalisation

B15 (900) Normalised to NIR

B2 (443) Un-normalised
Diffuser Aging

Diffuser Degradation process is linear

Diffuser aging is <1.5 % after 7 years in space

Spectral behaviour of diffuser aging (65 deg illumination)

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SIO Lw Anomaly at 510

Averaged anomaly on SIO (based on monthly means)

L510 - Common bins

IPF

Normalised

Not Normalised

L510 (mW/cm²/m/sr)

2003 2004 2005 2006 2007 2008 2009 2010

2010-04-21
Averaged anomaly on SIO (based on monthly means)
L555 - Common bins

- IPF
  - Old CAL
  - Normalised
  - Not Normalised

L555 (mW/cm²/m²sr)

2003 2004 2005 2006 2007 2008 2009 2010
Spectral Calibration

Overview

1. Diffuser based Spectral Calibration
   a) Spectral Features of Erbium doped diffuser
   b) Fraunhofer Lines on white diffuser

2. O2-A Spectral Campaigns

3. Spectral Stability

4. Instrument spectral model
Erbium Doped Diffuser

Acquisitions scenario:
Orbit \(n\) = Diffuser-1 Cal (Band setting \(j\))
Orbit \(n+1\) = Diffuser-Er (Band setting \(j\))

"Pink" Diffuser Measurements

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Erbium absorption spectrum
Erbium Results

**Method:** Correlate measurements with reference spectrum, corrected for Air-Vacuum changes (Edlen law)
Examples of Fraunhofer absorption spectrum
With MERIS spectral response overlay

Band settings (3 configurations)
Fraunhofer Results

Method: Spectrum-matching, with correction for Air-Vacuum (Edlen)

Line 2 Raw data: 5-cameras, 3 Fov

Results all Fraunhofer lines
For three orbits every six months, MERIS is configured to observe in detail the O2A absorption features.
Oxygen O2A Results

2 Methods

• A pressure minimization (LISE)
  Find the wavelength shift that minimises the dispersion in surface pressure retrieved from 7 O2A-campaign channels
  
• Spectrum-matching (FUB)
  Uses a neural net trained on a large number of radiative transfer computations
  
• Methods agree to better than 0.05nm)

When using O2A results for absolute spectral calibration, great care should be taken in the selection of the scene to be analyzed as the absorption spectrum is very sensitive to the underlying surface and “air-mass” seen. Desert targets have been selected for MERIS.
Camera 4 has stabilised with a spectral shift of 0.2 nm
Camera 2 has stabilised with a spectral shift of 0.14 nm
Similar results available using the O2A and Fraunhofer lines data
The shift is mainly wavelength independent
No spectral shift measured for Cameras 1,3,5 (all methods)
O2 and Fraunhofer confirm Erbium:
- C2 \( \Delta 0.15; \) C4 \( \Delta 0.2\text{nm}; \) C1 & C5 are stable
And add:
- C3 may have a slight negative shift
- Shifts are wavelength independent.
Results All Methods

Spectral shift from all data

[Graph showing spectral variations with data points and detector values.

- Spectral variation (+ arbitrary shift) [nm]
- Detector values: 864, 853, 762, 654, 587, 521, 484, 408, 394]
Simple instrument model where $k$ and $l$ stand for the spatial and spectral co-ordinates of a given detector respectively, the mean dispersion law—mainly linear—is a polynomial of order 3 (best fit), and, the across-track variation term, is a linear fit of the data at 395, 656 and 671nm expressed relative to its mean value.