MERIS Calibration

S. Delwart, L. Bourg, J-P Huot

OVERVIEW

1. Instrument & processing overview
2. Radiometric calibration method & results
   - Instrument degradation
   - Diffuser aging
3. Spectral Calibration method & results
   a) Spectral Features of Erbium doped diffuser
   b) Solar Fraunhofer Lines on white diffuser
   c) O2-A earth view Spectral Campaigns
   d) Instrument spectral model
   e) Spectral Stability
4. Instrument calibration vs Vicarious calibration

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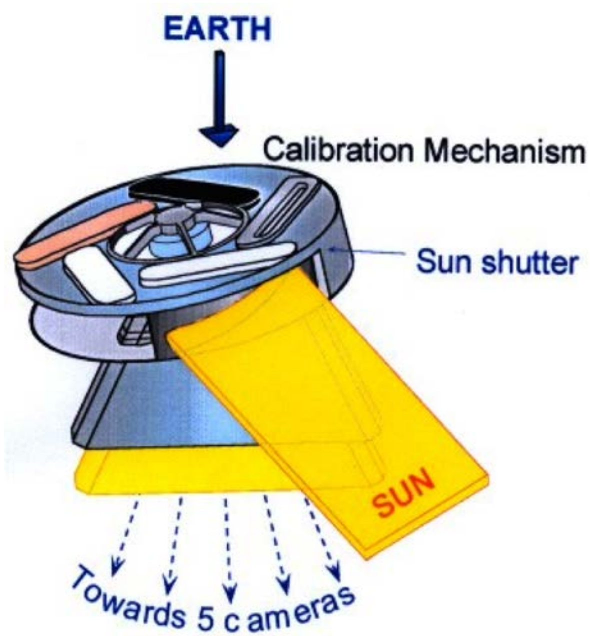
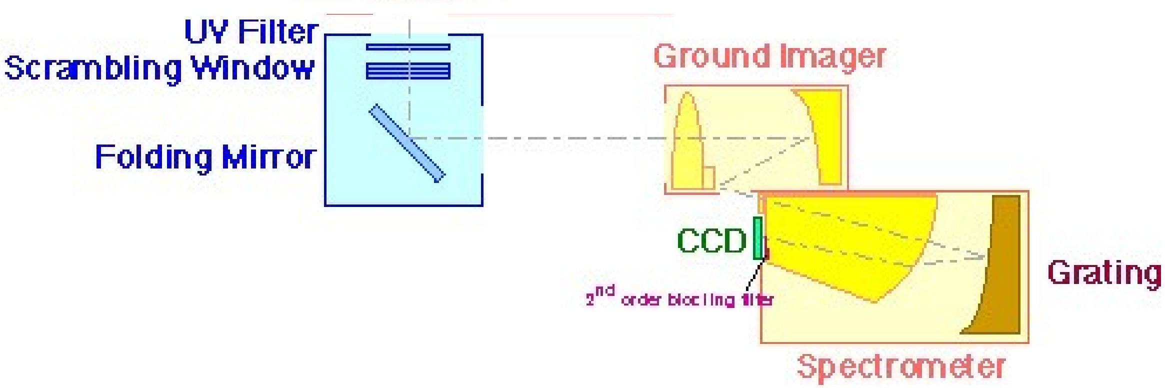
Instrument Overview



- Radiometric Calibration based on in-flight measurements
- Relies on Spectralon diffuser charaterisation (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

$$X_{b,k,m,f} = NonLin_{b,m}\left[g(T_f^{VEU}).\left[A_{b,k,m}.\left(L_{b,k,m,f} + G_{b,k,m}(L_{*,*,*,f}) \right) + Sm_{b,k,m,f}(L_{b,k,m,*}) \right] + g_c(T_f^{CCD}).C^0_{b,k,m} \right]$$

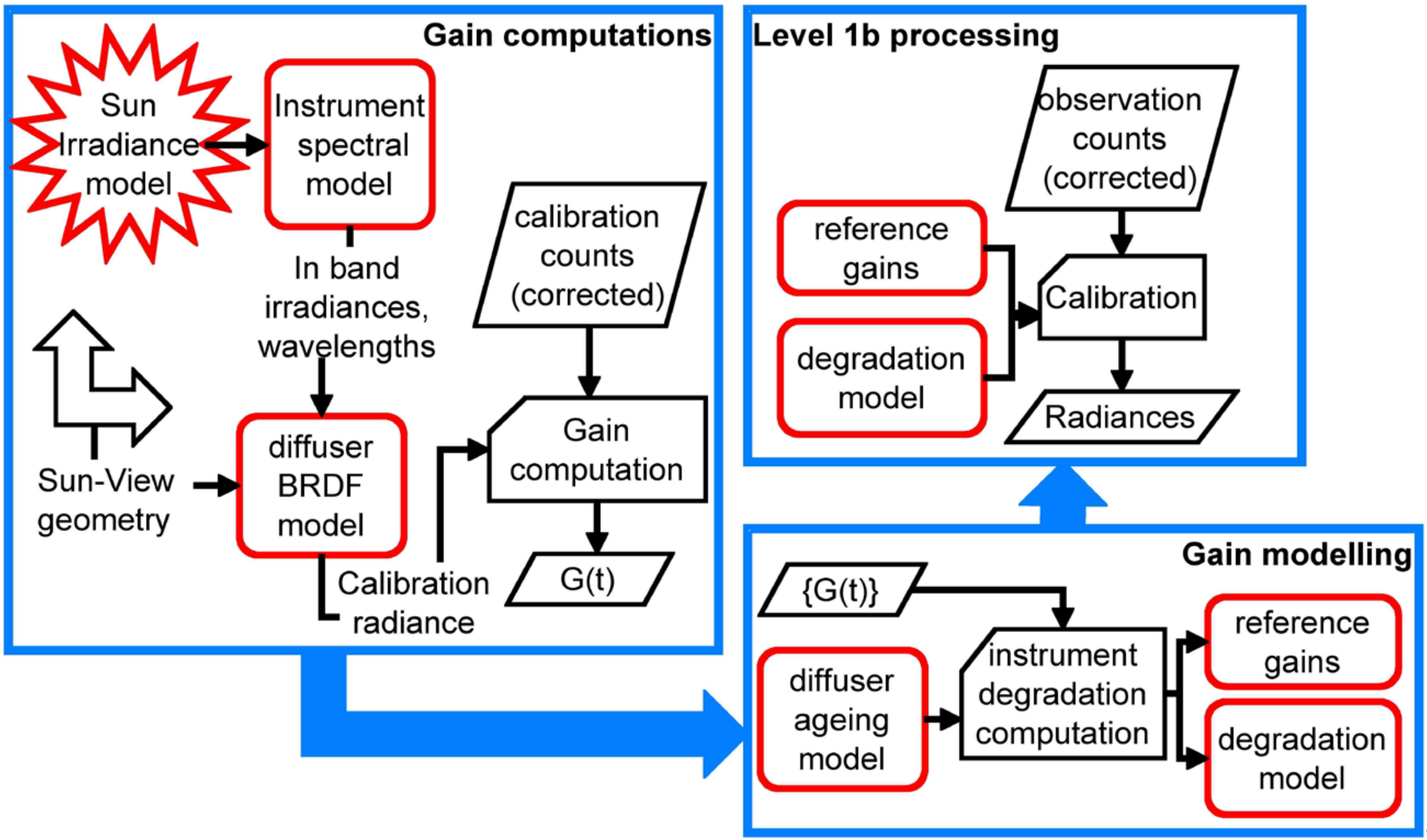
- $X_{b,k,m,f}$ is the MERIS raw sample,
- $NonLin_{b,m}$ is a non-linear function
- T_f^{VEU} is the temperature of the MERIS amplifiers (VEUs);
- T_f^{CCD} is the temperature of the MERIS detectors (CCDs)
- g(T) and gc(T) are (dimensionless) temperature correction functions;
- $AL_{b,k,m}$ the "absolute radiometric gain"
- $L_{b,k,m,f}$ the spectral radiance distribution in front of MERIS;
- $Sm_{b,k,m,f}$ 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;
- $G_{b,k,m}$ a linear operator representing the stray light contribution to the signal

Radiometric Approach

- Calibration modes provides instrument numerical counts $X_{cal}(l,k)$
- Instrumental corrections (non-linearity, dark offset, smear) yields $X'_{cal}(l,k)$
- Instrument Gain from $X'_{cal}(l,k) = G(l,k).L_{cal}(l,k)$
- 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 orbit and instrument pointing characterisation

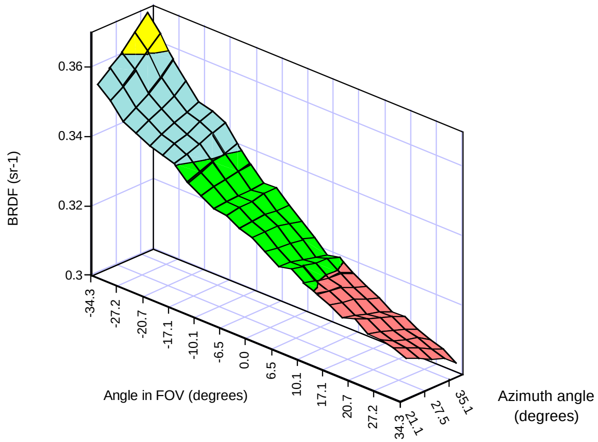
- Space environment implies ageing of Diffuser and Optics
  - 2nd diffuser to monitor diffuser-1 BRDF ageing
    => Diffuser Aging model
  - frequent calibration to monitor Instrument degradation
    => instrument degradation model

Radiometric Processing

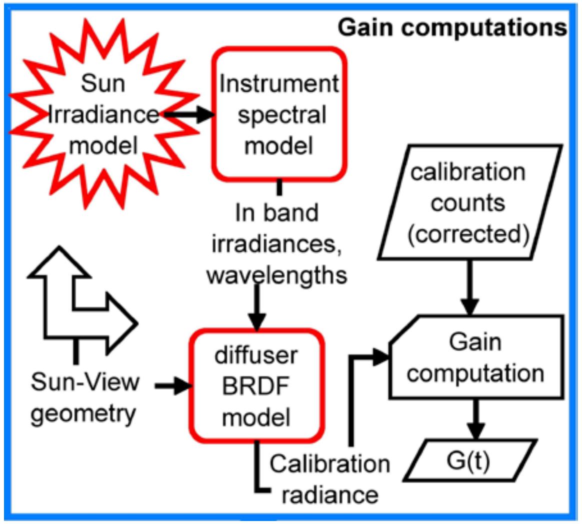


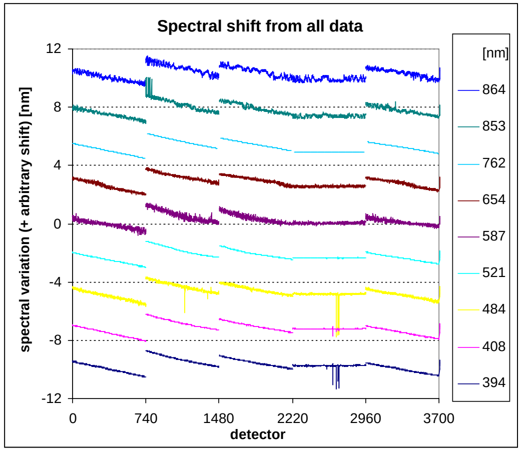
Radiometric Calibration

Key Inputs

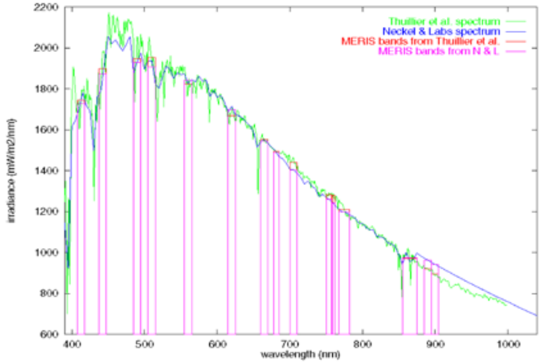


On-ground characterisation of diffuser-1 @ 410nm





On- Orbit Spectral characterisation measurements (Erbium Doped diffuser, Fraunhofer lines, O2-A)



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

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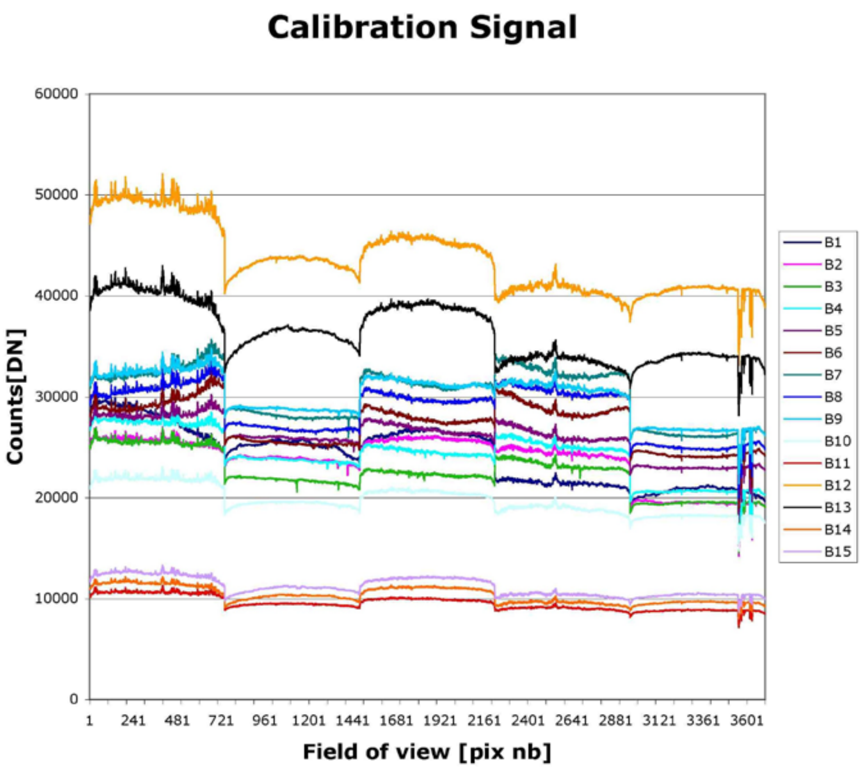
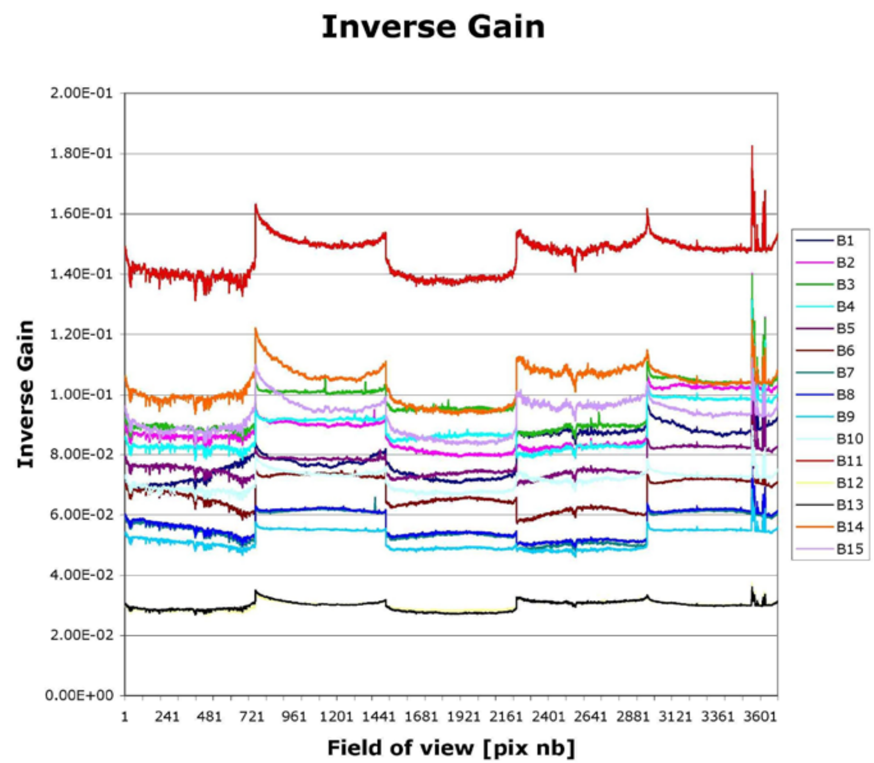
Radiometric Calibration

Results

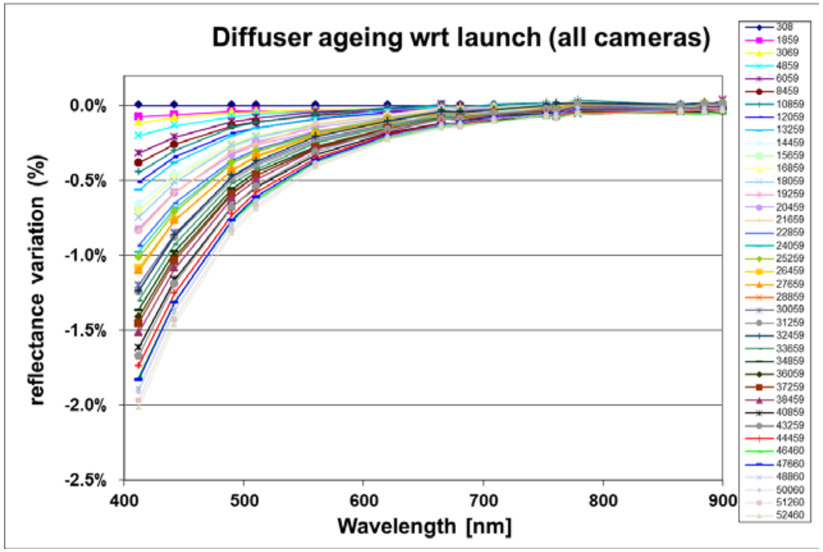


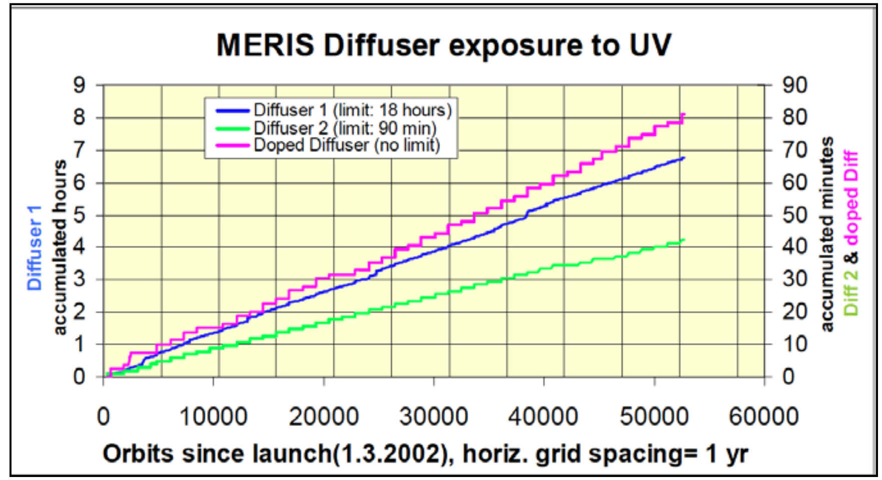
Radiometric Calibration raw digital counts



Corresponding Radiometric “Gain” Coefficients

Diffuser Aging

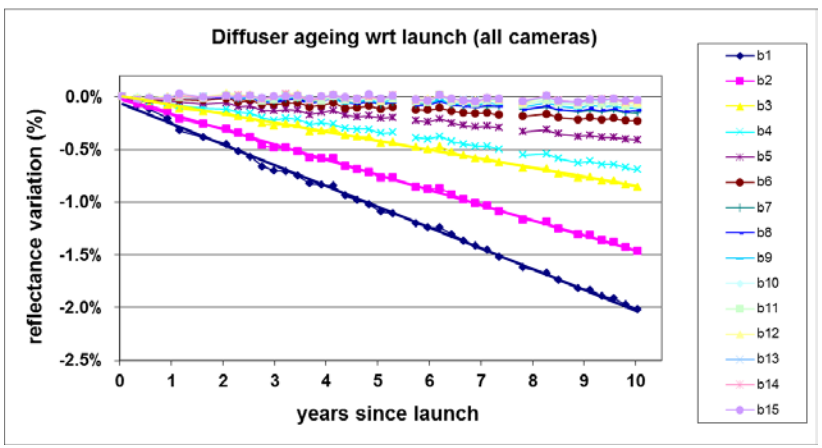




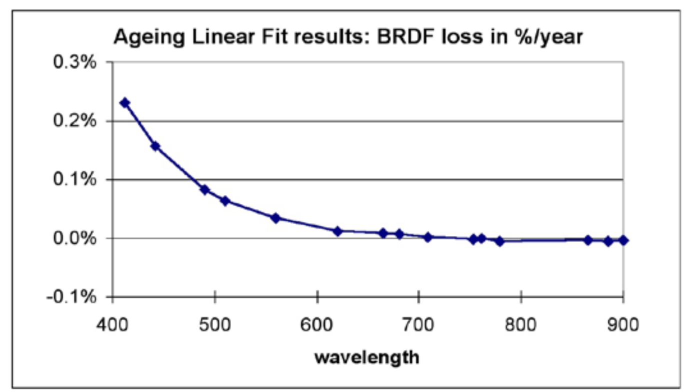
Diffuser's UV exposure
(Dif-1 [hrs], Dif-2 & doped[min])

Degradation of Diffuser-1 vs Diffuser-2

Diffuser aging is <2 % after than 10 years in space

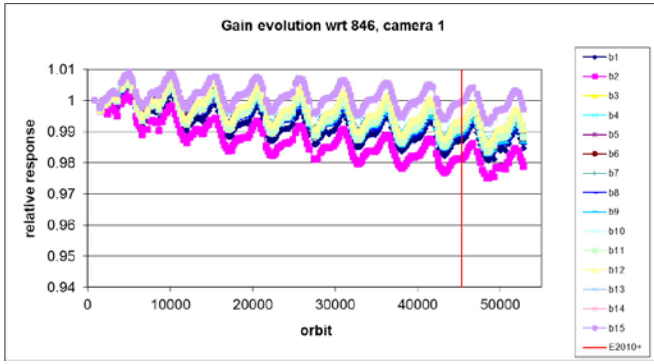


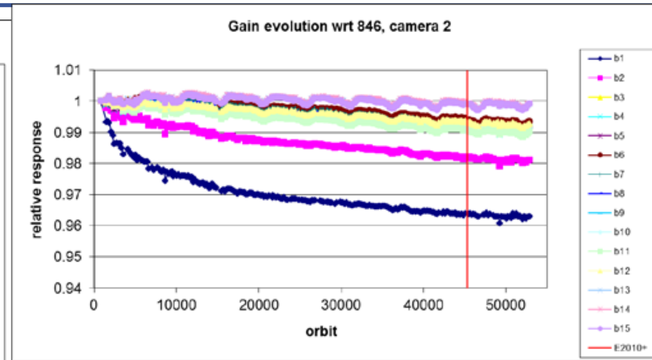
Diffuser Degradation process is linear

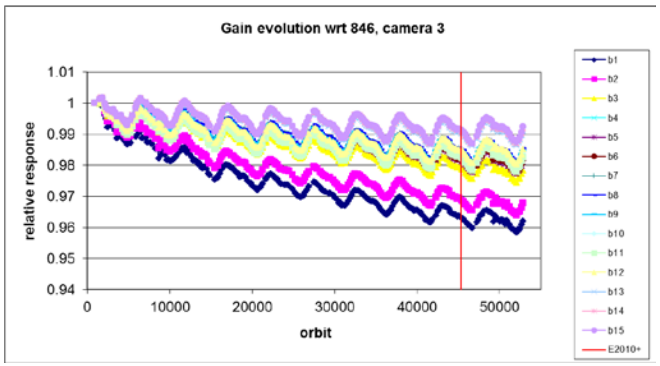


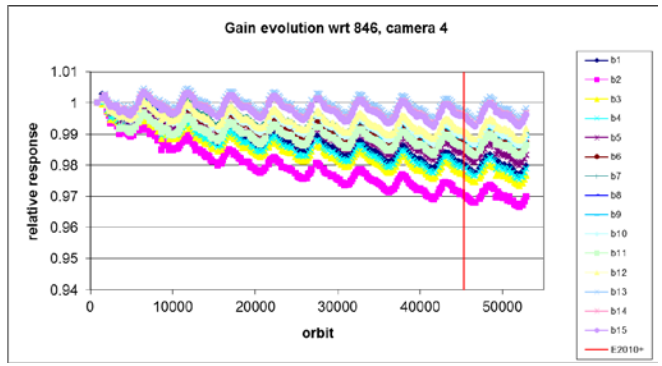
Diffuser Degradation rate per year
(65deg illumination)

Instrument Degradation

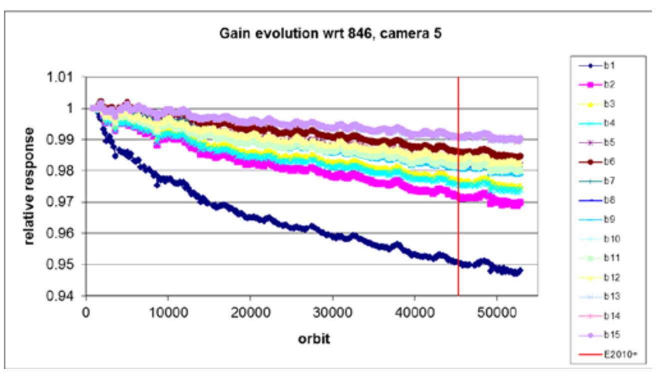


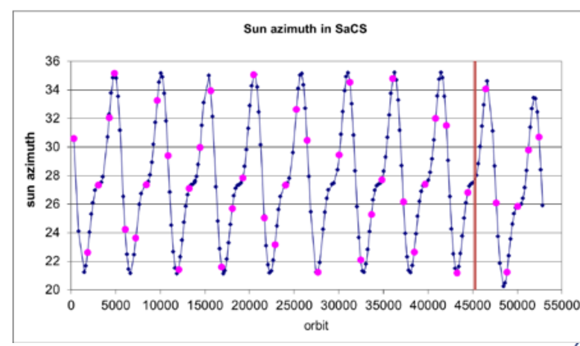






Maximum degradation < 5 %
After 10 years in space





Diffuser illumination

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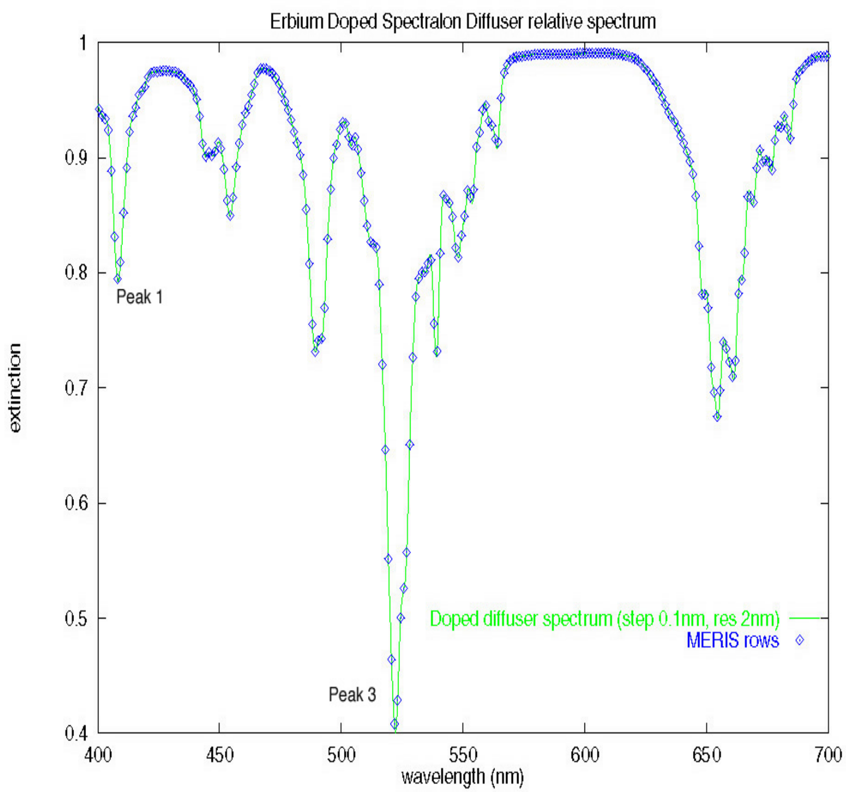
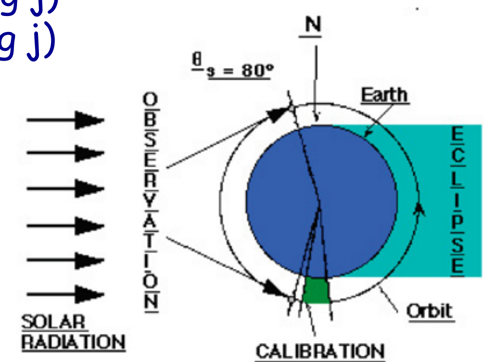
Erbium Doped Diffuser

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



Erbium absorption spectrum

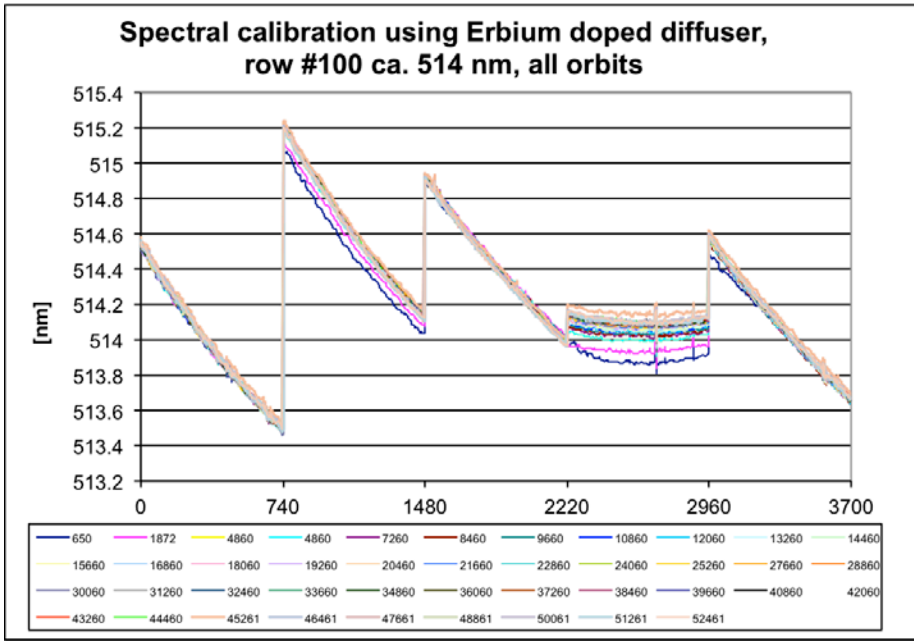


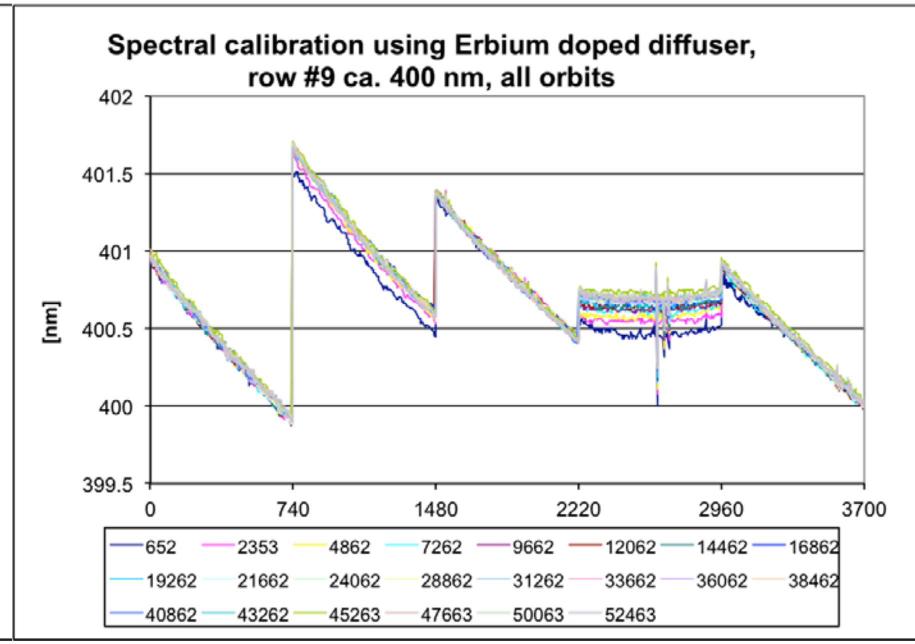
"Pink" Diffuser Measurements

centre	width (nm)	centre	width (nm)
400.625	1.25	514.375	1.25
401.875	1.25	515.625	1.25
403.125	1.25	516.875	1.25
404.375	1.25	518.125	1.25
405.625	1.25	519.375	1.25
406.875	1.25	520.625	1.25
408.125	1.25	521.875	1.25
409.375	1.25	523.125	1.25
410.625	1.25	524.375	1.25
411.875	1.25	525.625	1.25
413.125	1.25	526.875	1.25
414.375	1.25	528.125	1.25
415.625	1.25	529.375	1.25
416.875	1.25	530.625	1.25
418.125	1.25	531.875	1.25

Band settings j

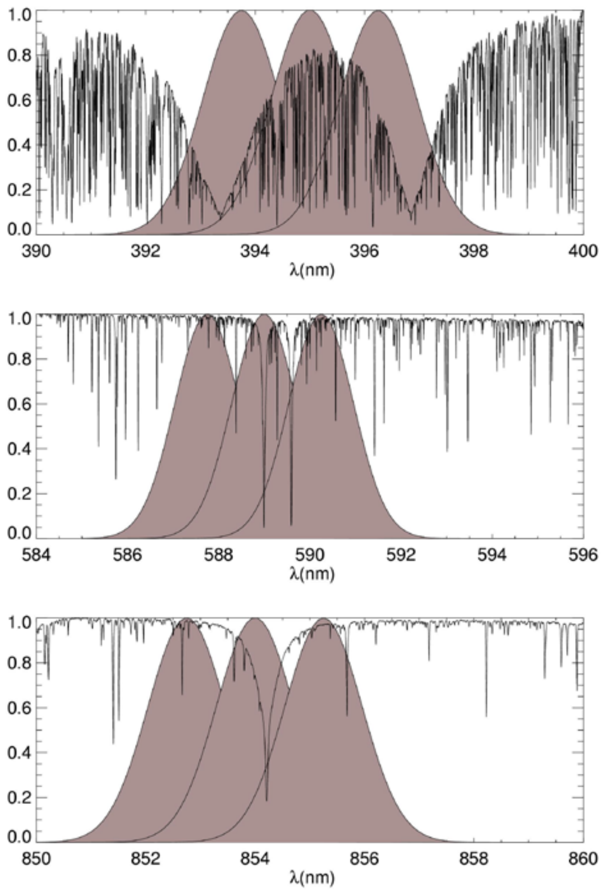
Erbium Results



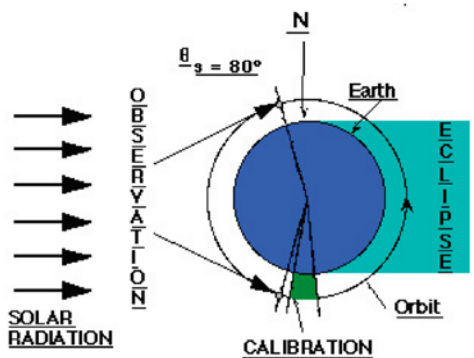


Method: Determine the position of the absorption peak in pixel number, with correction for Air-Vacuum changes (Edlen)

Fraunhofer Lines



Examples of Fraunhofer absorption spectrum
With MERIS spectral response overlay



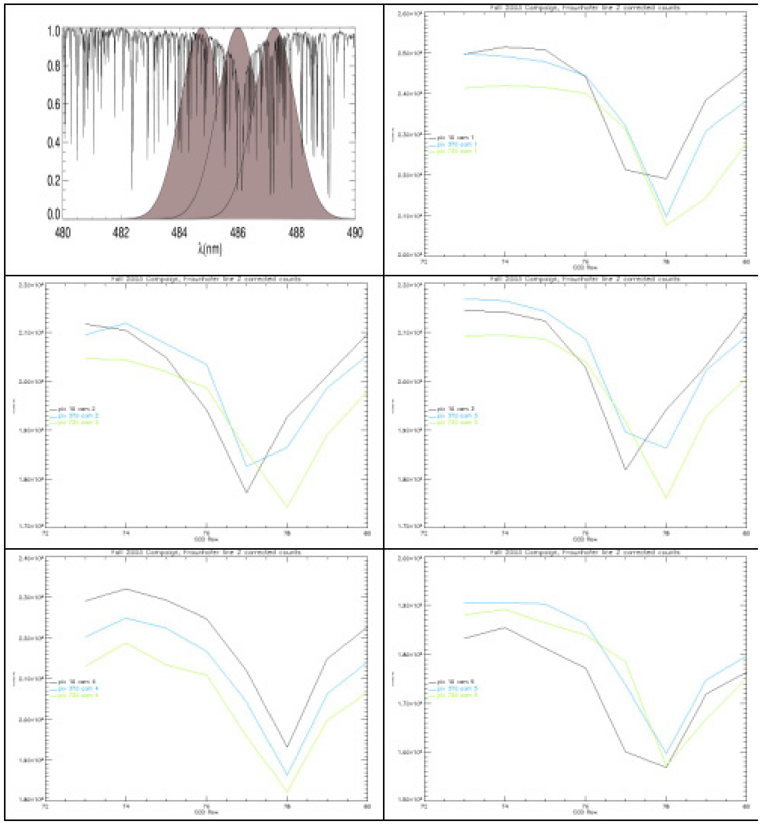
White diffuser-1 measurement

line 1 (393nm)	line 2 (485nm)	line 3 (588nm)	line 4 (655nm)	line 5 (855nm)	line 6 (867nm)
393.125	480.625	584.375	653.125	850.625	863.125
394.375	481.875	585.625	654.375	851.875	864.375
395.625	483.125	586.875	655.625	853.125	865.625
396.875	484.375	588.125	656.875	854.375	866.875
398.125	485.625	589.375	658.125	855.625	868.125
399.375	486.875	590.625	659.375	856.875	869.375
400.625	488.125	591.875	660.625	858.125	870.625
	489.375	593.125			

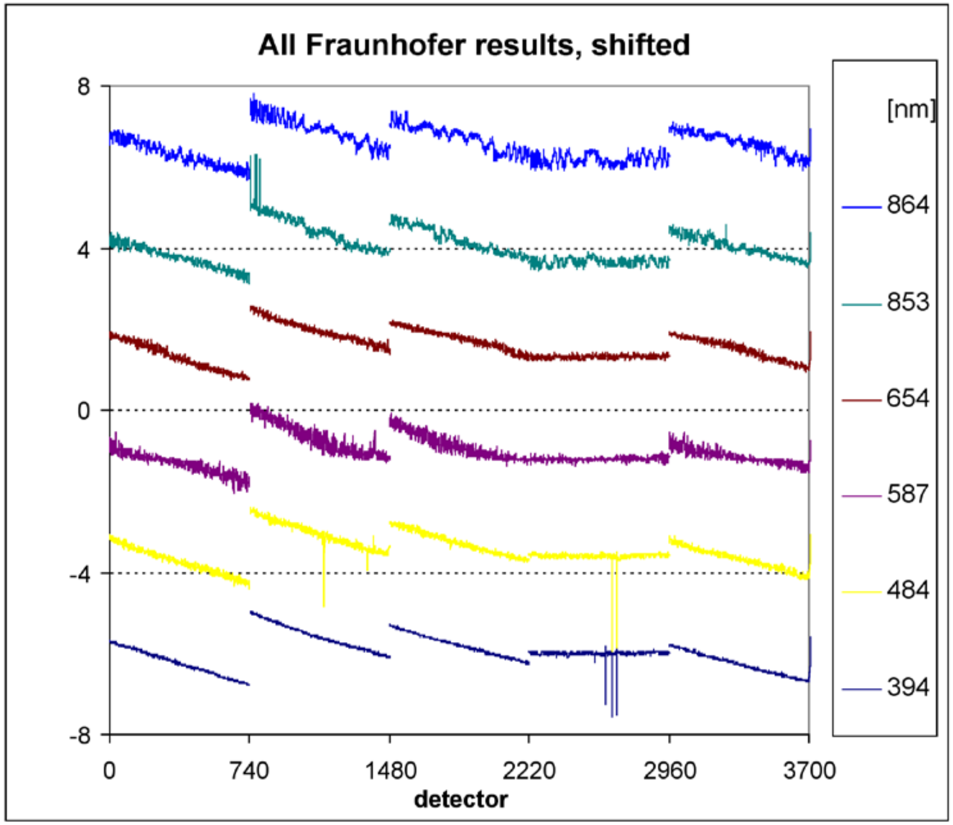
Band settings (3 configurations)

Fraunhofer Results

Line 2 Raw data: 5-cameras, 3 Fov



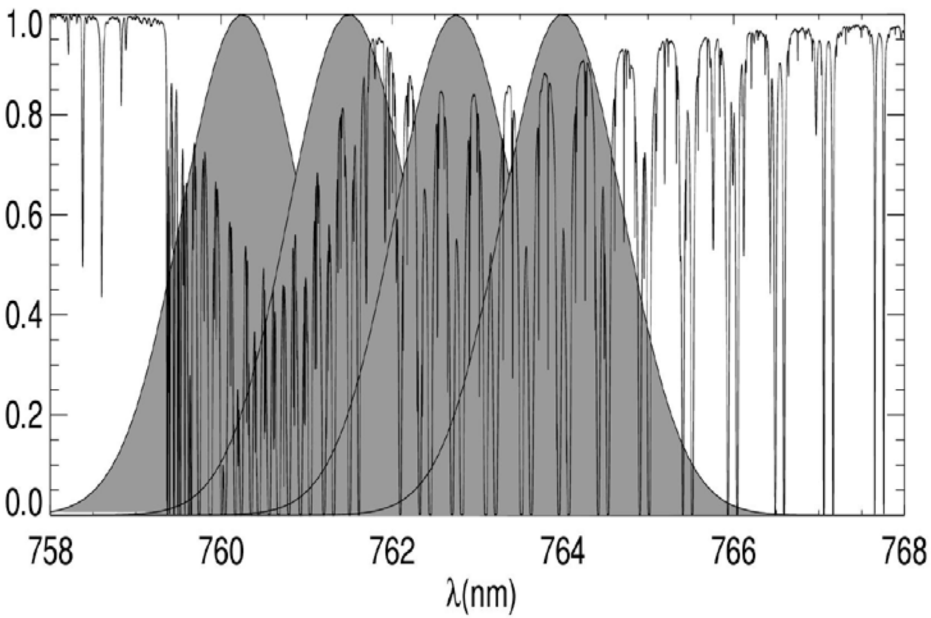
Results all Fraunhofer lines



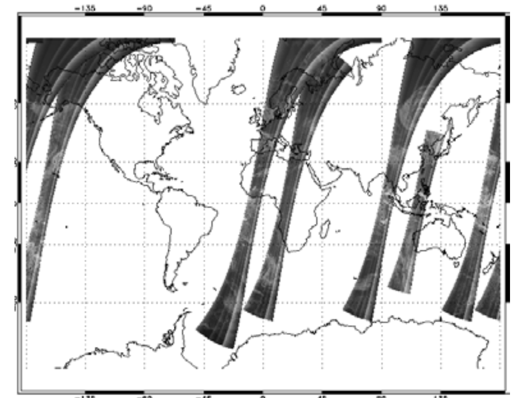
Method: Spectrum-matching, with correction for Air-Vacuum (Edlen)

Oxygen O2A

For three orbits every six months, MERIS is configured to observe in detail the O2A absorption features



Oxygen O2A absorption spectrum
MERIS spectral response overlay

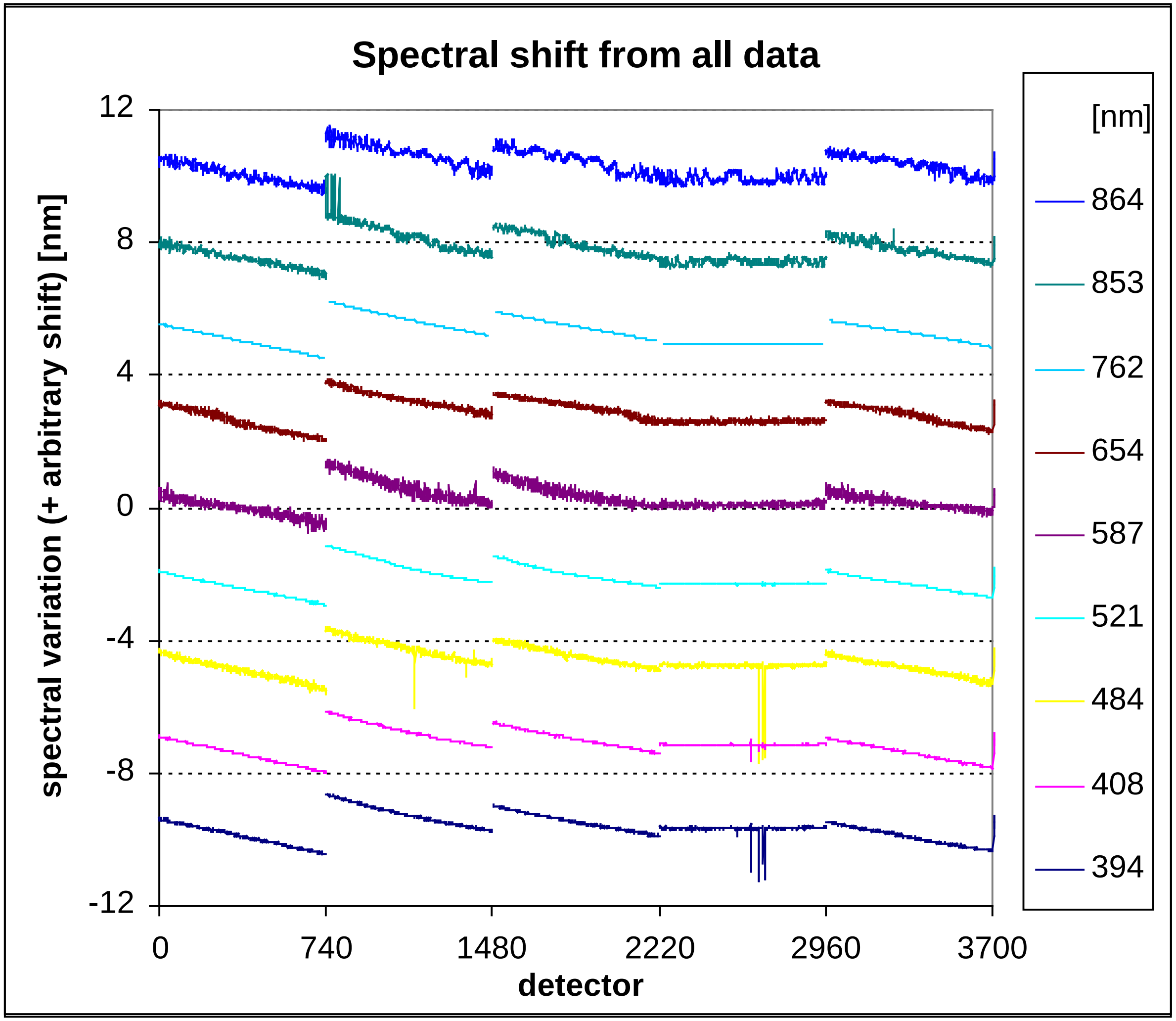


Measurements over Natural target

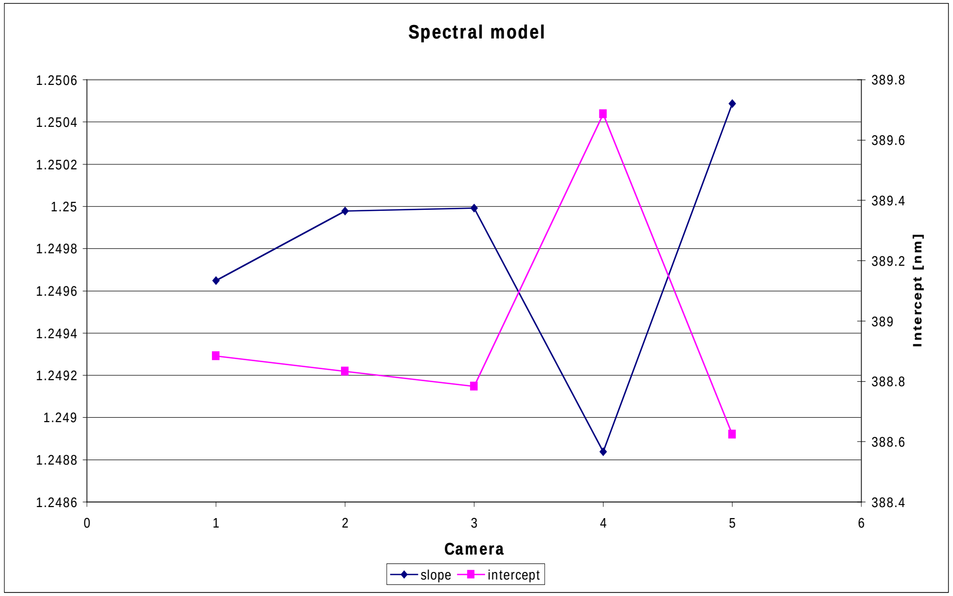
name	centre	width (nm)
blue-2	442.5	10
red-1	665	10
ref-1	753.125	6.25
O2-0	758.125	1.25
O2-1	759.375	1.25
O2-2	760.625	1.25
O2-3	761.875	1.25
O2-4	763.125	1.25
O2-5	764.375	1.25
O2-6	765.625	1.25
O2-7	766.875	1.25
O2-8	768.125	1.25
O2-9	769.375	1.25
ref-2	778.75	7.5
IR-1	865	10

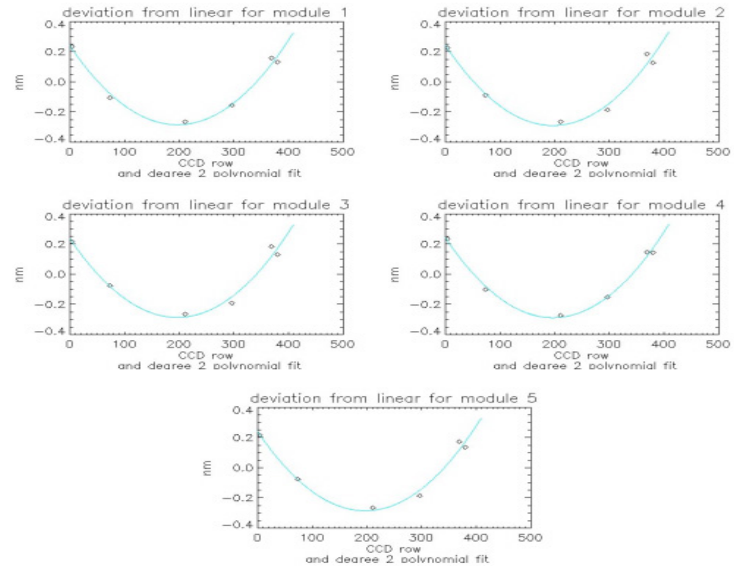
O2A Campaign Band setting

Results All Methods



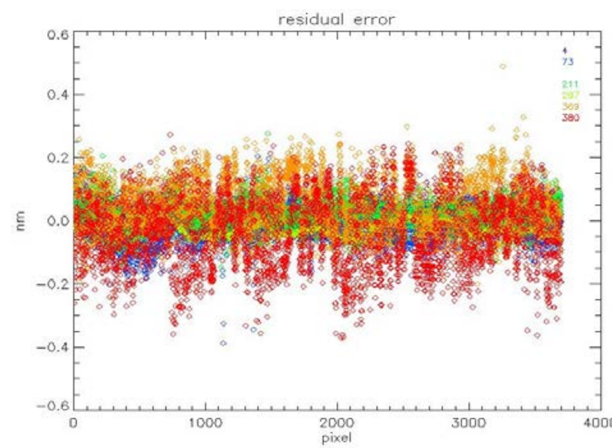
Instrument Model





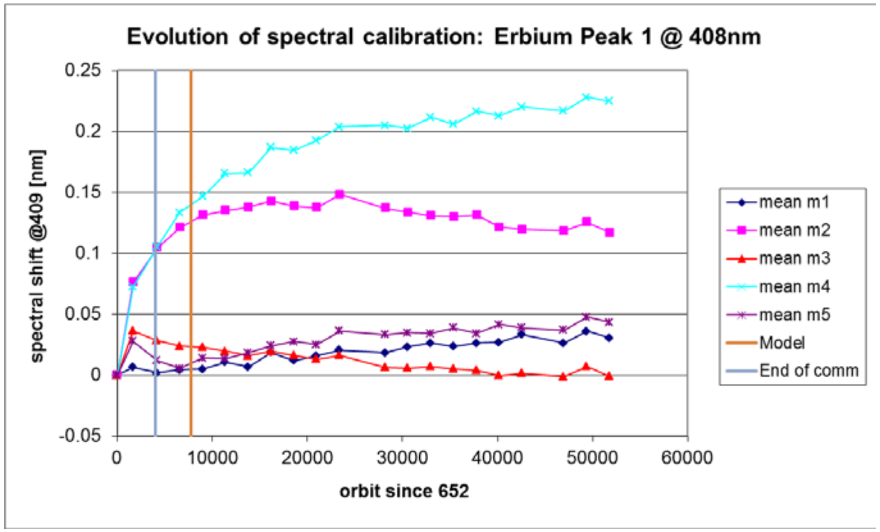
$$\lambda(k,l) = \bar{\lambda}(l) + \Delta\lambda(k)$$

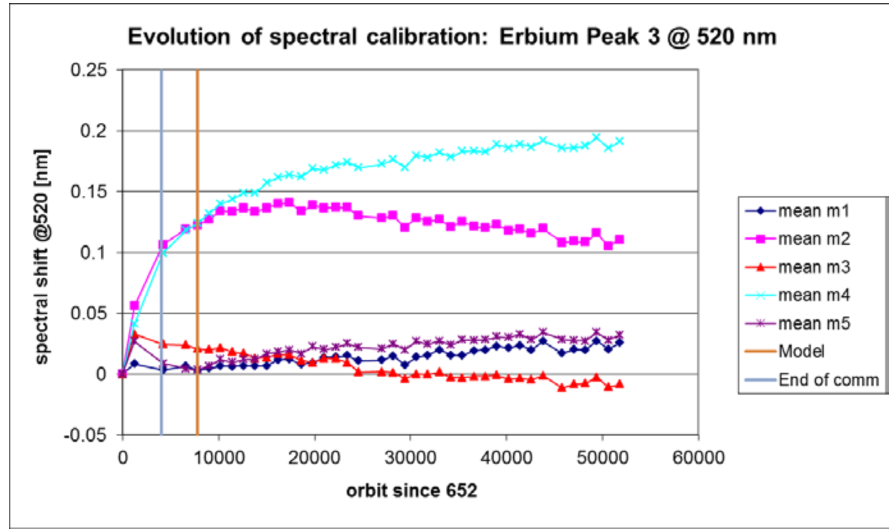
Simple instrument model where *k* and *l* stand for the spatial and spectral co-ordinates of a given detector respectively , the mean dispersion law –mainly linear– is a polynomial of order 3 (best fit), and, the across-track variation term, is a linear fit of the data at 395, 656 and 671nm expressed relative to its mean value



Spectral Stability

Erbium doped diffuser measurements





Spectral stability since end of commissioning is:

- Camera 4 has drifted by less than 0.12 nm
- Camera 2 has drifted by less than 0.08 nm
- Camera 1, 3 & 5 have drifted by less than 0.05 nm

No spectral drift correction is included in the processing as the spectral model, based on Fall 2003 data (orbit ~7800), is representative of the complete mission.

MERIS Calibration Summary

1. In-flight spectral measurements → instrument spectral model

$$\lambda(k,l) = \overline{\lambda}(l) + \Delta\lambda(k)$$

2. In-band spectral irradiance per pixel by integration of Thuillier et al Solar Irradiance

3. Diffuser BRDF model (Rahman) fitted on charaterisation data, interpolated spetrally from char. Wavelengths to MERIS bands

4. Compute instantaneous 'gain' factors for each calibration acquisition (every two weeks)

5. Correct for diffuser ageing

6. Model time evolution as per Barnes et al:

   G(t0): gain at orbit 297, β: amplitude, δ^{-1}: time constant, γ: ⇔ time offset at orbit 297

$$G(t) = G(t_0)\cdot(1-\beta\cdot(1-\gamma\cdot e^{-\delta t}))$$

Conclusions

The Radiometric calibration of MERIS is obtained from a well protected on-board diffuser plate, used as a secondary standard

The stability (aging) of the diffuser plate is monitored by the second diffuser plate deployed 10 time less frequently. Results show Diff-1 to have aged <2% => an aging of <0.2% for Diff-2.

The precise knowledge of the instrument spectral characteristics is obtained from regular spectral calibration campaigns and a simple instrument spectral model with an accuracy of <0.2nm, and have shown the instrument to be stable to better than 0.1 nm over 10 years.

The instrument degradation (trending) has been monitored and showed that Meris has degraded by < 5% in the blue and < 1 % in the red NIR.

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Calibration vs corrections

Calibration = DN ➔ $Wsr^{-1}nm^{-1}m^{-2}$

L1 Processing:

Smear correction

Non-Linearity

Dark-Offset

Gains: Spectral Cal.

Instrument Gains

Inst. Degradation

Diffuser Aging

Straylight

Geometry

L2 Processing:

Gaseous Transmission

Smile correction

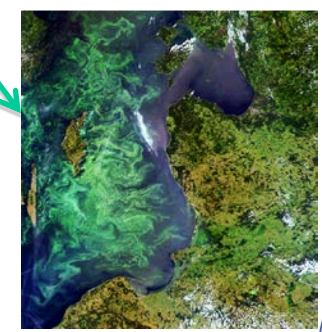
Rayleigh

Aerosols

Glint

Gothic R

Ocean Color



Calibration vs corrections

Vicarious Calibration

W $sr^{-1}nm^{-1}m^{-2}$ ⇨ W′ $sr^{-1}nm^{-1}m^{-2}$

?

L1 Processing:
- Smear correction
- Non-Linearity
- Dark-Offset
- Gains: Spectral Cal.
- Instrument Gains
- Inst. Degradation
- Diffuser Aging
- Straylight
- Geometry

Calibration

DN ⇨ W $sr^{-1}nm^{-1}m^{-2}$

L2 Processing:
- Gaseous Transmission
- Smile correction
- Rayleigh
- Aerosols
- Glint
- Gothic R
- Ocean Color

Forward

mg/L ⇨ W′ $sr^{-1}nm^{-1}m^{-2}$

Calibration vs corrections

OC requires Vicarious Calibration … today

However

Use of Vicarious Calibration blindly
does not allow for improvements
in either L1 and L2 processing.

Vicarious Calibration should first be used
to better understand the limitations of L1 and L2
processing, leading to improved instrument corrections and geophysical modeling
and only then used for final adjustment
only if needed.