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Impact of the spectral response variations on Sentinel-2C TOA reflectance

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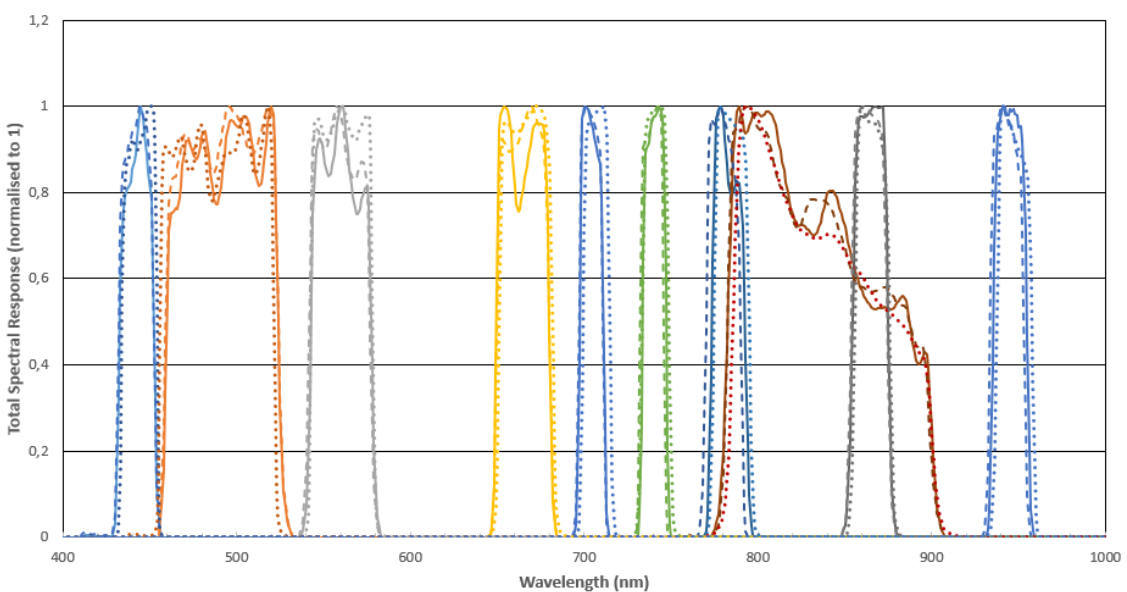
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(3) Starion Group for ESA ESRIN, Frascati, Italy (4) European Space Agency-ESRIN, Frascati, Italy*

7th Sentinel-2 Validation Team Meeting

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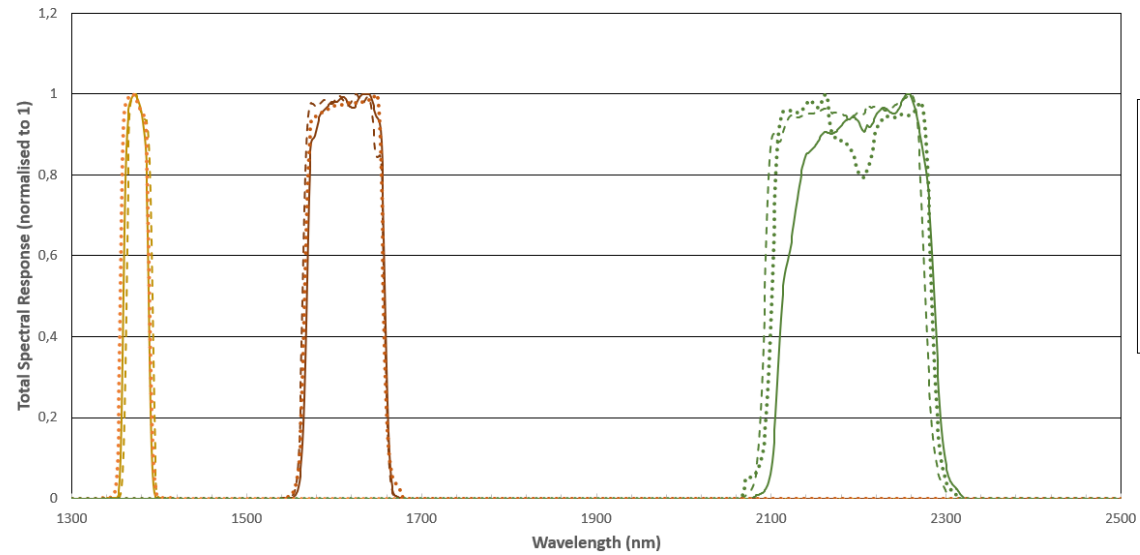
S2A, S2B & S2C MSI Spectral Response Average - VNIR



- S2A_SR_AV_B1
- S2A_SR_AV_B2
- S2A_SR_AV_B3
- S2A_SR_AV_B4
- S2A_SR_AV_B5
- S2A_SR_AV_B6
- S2A_SR_AV_B7
- S2A_SR_AV_B8
- S2A_SR_AV_B8A
- S2A_SR_AV_B9
- - S2B_SR_AV_B1
- - S2B_SR_AV_B2
- - S2B_SR_AV_B3
- - S2B_SR_AV_B4
- - S2B_SR_AV_B5
- - S2B_SR_AV_B6
- - S2B_SR_AV_B7
- - S2B_SR_AV_B8
- - S2B_SR_AV_B8A
- - S2B_SR_AV_B9
- ... S2C_SR_AV_B1
- ... S2C_SR_AV_B2
- ... S2C_SR_AV_B3
- ... S2C_SR_AV_B4
- ... S2C_SR_AV_B5
- ... S2C_SR_AV_B6
- ... S2C_SR_AV_B7
- ... S2C_SR_AV_B8
- ... S2C_SR_AV_B8A
- ... S2C_SR_AV_B9

- ❖ Sentinel-2 ISRF as provided to users
- ❖ Average spectral responses from various characterisations over the FOV

S2A, S2B & S2C MSI Spectral Response Average - SWIR



- S2A_SR_AV_B10
- S2A_SR_AV_B11
- S2A_SR_AV_B12
- - S2B_SR_AV_B10
- - S2B_SR_AV_B11
- - S2B_SR_AV_B12
- ... S2C_SR_AV_B10
- ... S2C_SR_AV_B11
- ... S2C_SR_AV_B12



❖ For S2C, AIRBUS provided information on change of ISRF as a function of the pixel number

✓ Max shift in CWL ~ 1 nm for VNIR bands

✓ Highest range of variation: B08

✓ Max shift in CWL ~ 3 - 4 nm for SWIR bands

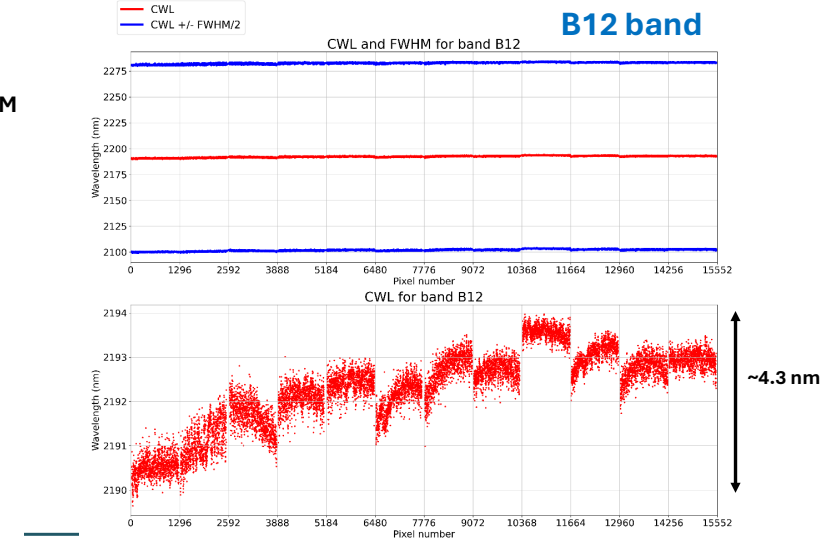
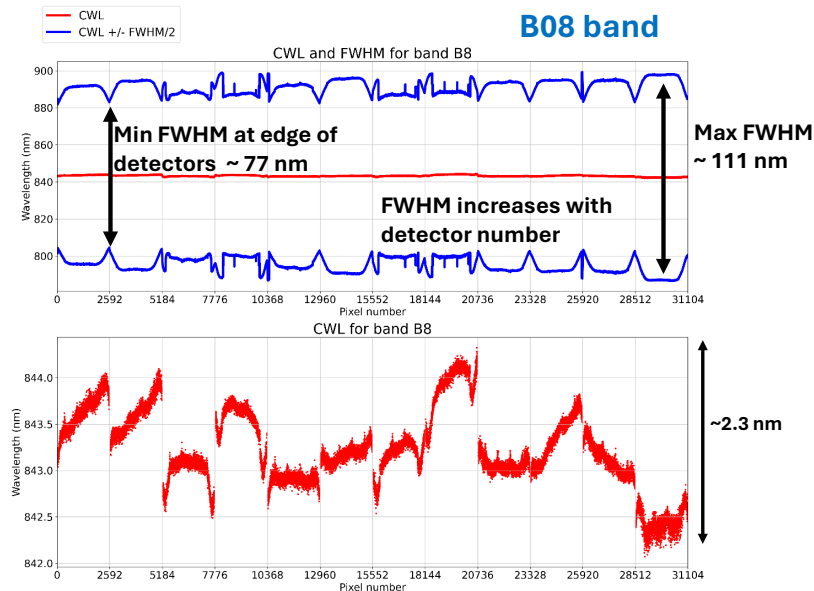
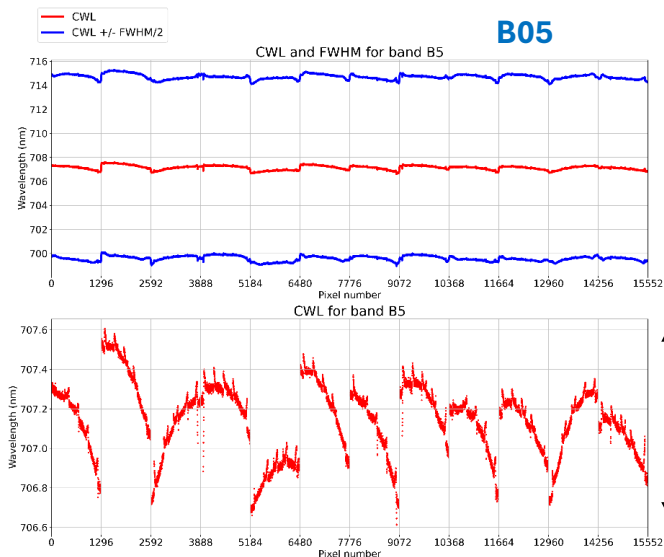
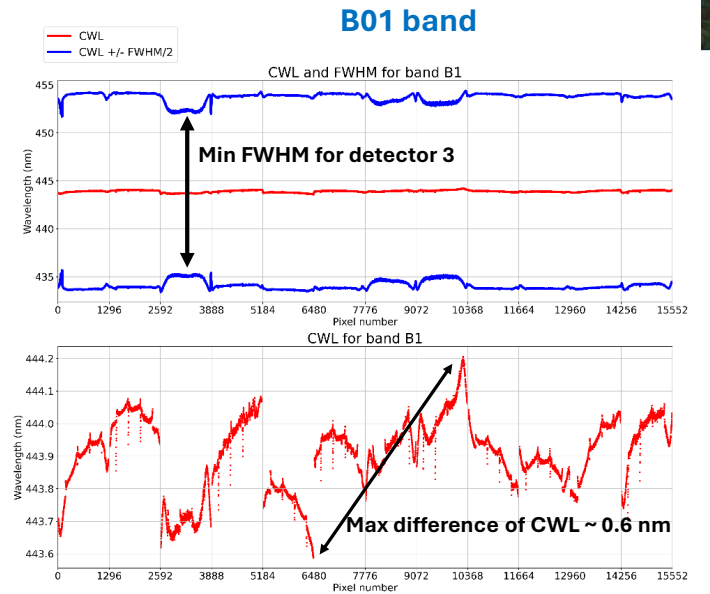
Statistics on central wavelengths (CWL) and full width at half maximum (FWHM)

		CWL (nm)					FWHM (nm)				
		min	avg	max	max-min	std	min	avg	max	max-min	std
	B01	443.6	443.9	444.2	0.6	0.11	16.0	19.7	20.6	4.6	0.91
	B02	488.3	488.7	489.2	0.9	0.15	63.8	65.0	65.5	1.8	0.26
	B03	560.0	560.5	560.9	0.8	0.15	33.8	35.0	35.5	1.7	0.31
	B04	666.2	666.6	666.9	0.6	0.10	28.9	30.0	30.5	1.6	0.27
	B05	706.6	707.1	707.6	1.0	0.18	14.7	15.1	15.5	0.8	0.22
	B06	740.6	741.1	741.4	0.7	0.16	14.9	15.1	15.5	0.6	0.14
	B07	784.3	785.1	785.6	1.3	0.21	19.5	20.0	20.6	1.1	0.32
Broad band	B08	842.1	843.2	844.3	2.3	0.41	77.5	96.3	111.6	34.1	7.93
Narrow band	B8A	865.5	865.9	866.3	0.8	0.16	19.0	19.9	20.5	1.5	0.31
	B09	947.2	947.8	948.3	1.2	0.20	19.2	19.8	20.5	1.3	0.31
	B10	1370.7	1372.4	1374.1	3.4	0.91	32.7	32.9	33.4	0.7	0.14
	B11	1609.8	1611.1	1613.1	3.3	0.76	75.5	89.3	89.9	1.4	0.21
	B12	2189.6	2192.3	2194.0	4.3	0.88	179.0	180.8	183.1	4.1	0.50



- ❖ Not regular changes of the CWL as a function of the pixel
 - ✓ Transitions from one detector to another
 - ✓ inter-pixel fluctuations : likely measurement uncertainties
-
- ❖ What is the impact on TOA reflectance ?

CWL (red line) and FWHM (blue line, as $WCL \pm FWHM/2$)





❖ Simulation of observations :

✓ Uniform target :

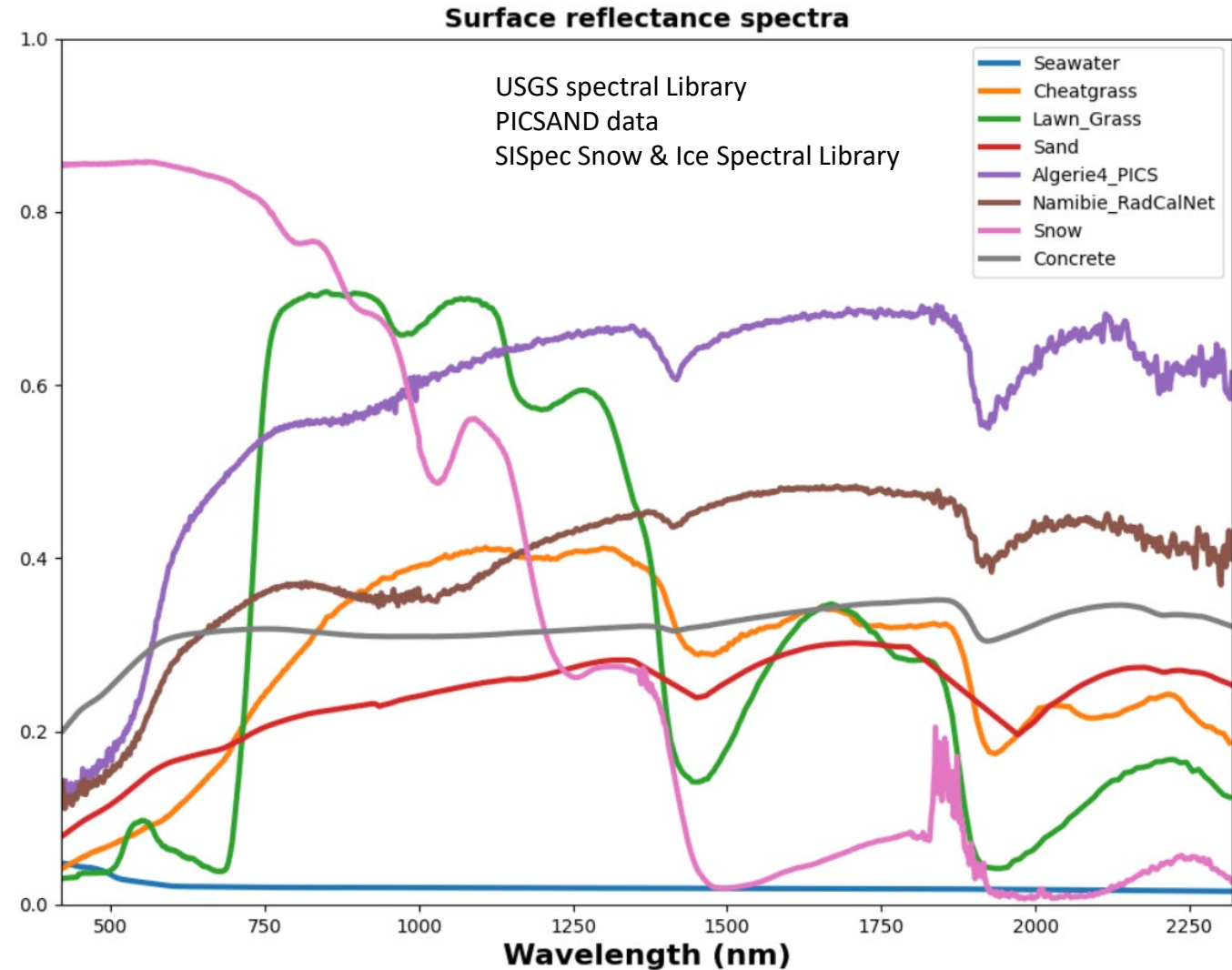
- 8 surfaces spectra
- Same scene over all the pixels

✓ Atmosphere

- Pressure: 1013 mbar
- Continental aerosols: $AOT_{550} = 0.2$
- Ozone: 350 Db
- Water vapour: 3 g/cm²

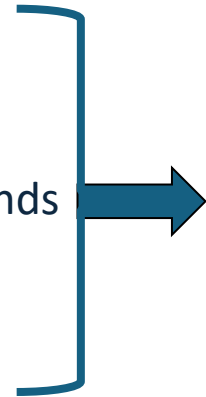
✓ Sun zenith angle : 40°

✓ Viewing direction : Nadir



❖ Radiative transfer code: SOS-ABS (<https://github.com/CNES/RadiativeTransferCode-SOS>)

- ✓ Scattering
- ✓ Absorption: CKD method
 - Spectral resol.: 10 cm^{-1} for VNIR / 5 cm^{-1} for SWIR bands
- ✓ Surface reflection
- ✓ Polarisation



Spectra of TOA reflectance: $\rho_{simu}^{TOA}(\lambda)$



Solar irradiance spectrum

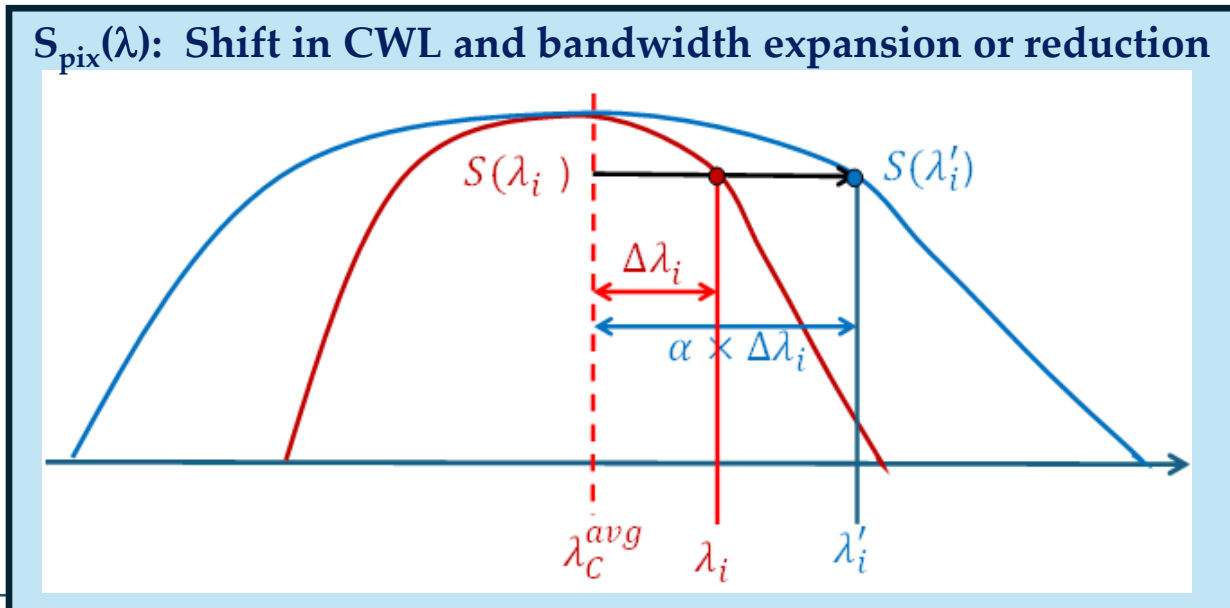
Spectra of TOA radiance: $L_{simu}^{TOA}(\lambda)$



Convolution on the ISRF per pixel

TOA radiance per spectral band and pixel

$$L_{pix}^{TOA}(p) = \frac{\int_0^{\infty} L_{simu}^{TOA}(\lambda) \cdot S_{pix}(\lambda) \cdot d\lambda}{\int_0^{\infty} S_{pix}(\lambda) \cdot d\lambda}$$





❖ Impact of ISRF variations in equalisation coefficients must be considered:

- ✓ RT simulations give the information on what is seen by each pixel
- ✓ S2C measurements are equalised
- ✓ Sun-diffuser acquisitions are also impacted by change in ISRF vs the pixel
 - ➔ estimated equalisation coefficients include the ISRF variation

Sun-diffuser

➔ considered spectrally invariant

$$L_{simu}^{SD}(\lambda) = \rho_{dif}(\lambda) \times E_{sun}(\lambda)$$



Convolution on the ISRF per pixel

$$L_{pix}^{SD}(p) = \frac{\int_0^\infty L_{simu}^{SD}(\lambda) \cdot S_{pix}(\lambda) \cdot d\lambda}{\int_0^\infty S_{pix}(\lambda) \cdot d\lambda}$$



Contribution of the spectral variation in equalisation coefficients

$$coef(p) = \frac{L_{pix}^{SD}(p)}{\langle L_{pix}^{SD}(p) \rangle} \quad \text{mean value over pixels}$$



Introduction in TOA radiance simulations

$$L_{equal}^{TOA}(p) = \frac{L_{pix}^{TOA}(p)}{coef(p)}$$

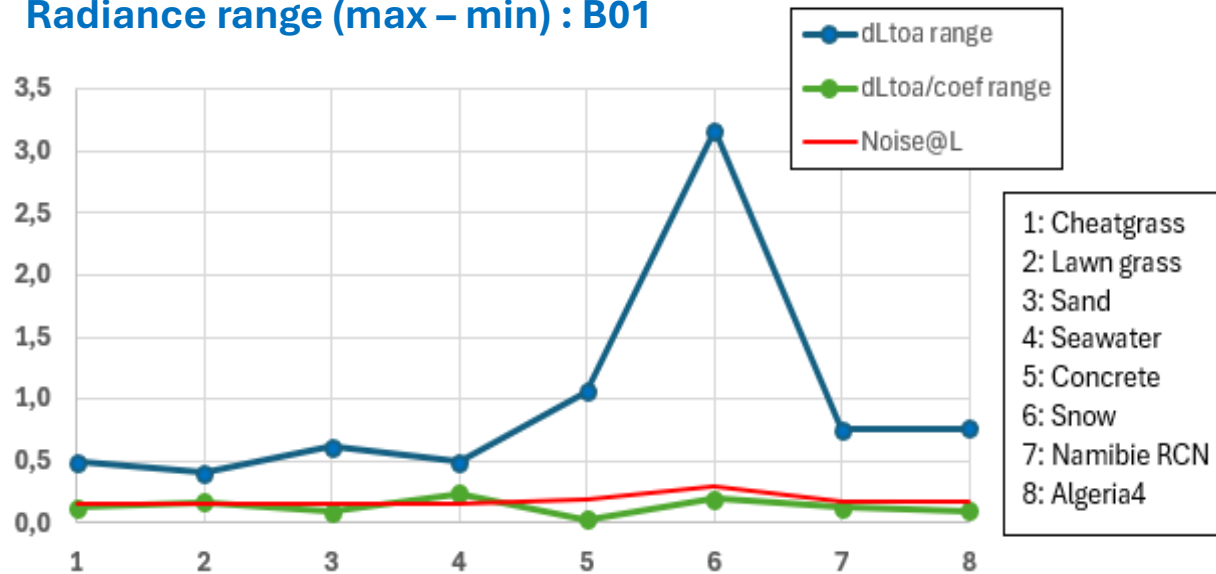


❖ Difference between radiance for ISRF(p) and radiance for the average ISRF

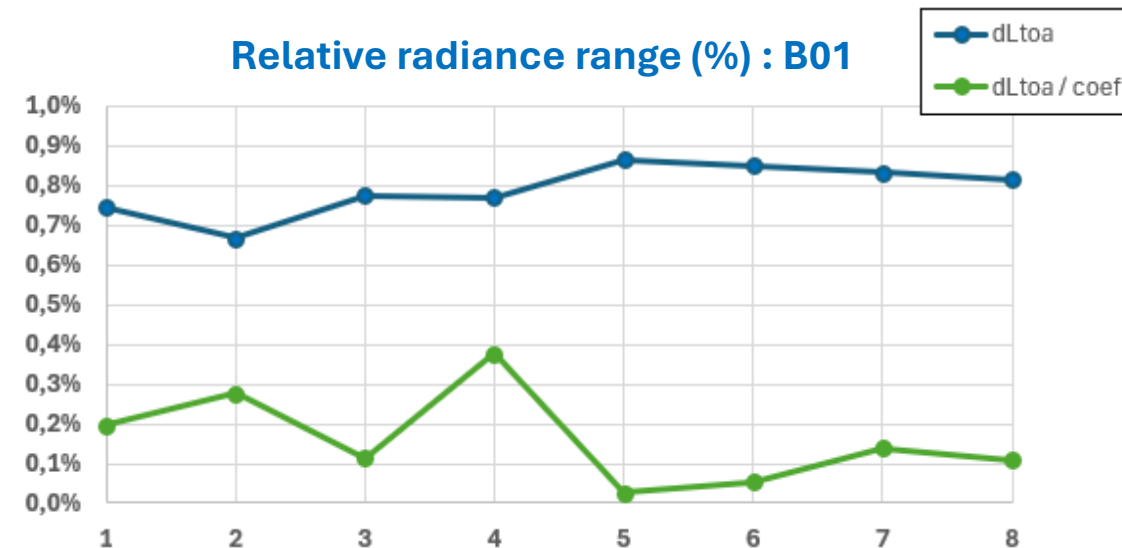
✓ **B01 band (443.9 nm) : $\Delta CWL_{max} = 0.6 \text{ nm}$**

- dLtoa range
- dLtoa/coef range : efficiency of the compensation by equalisation coefficients
- Radiometric noise

Radiance range (max – min) : B01



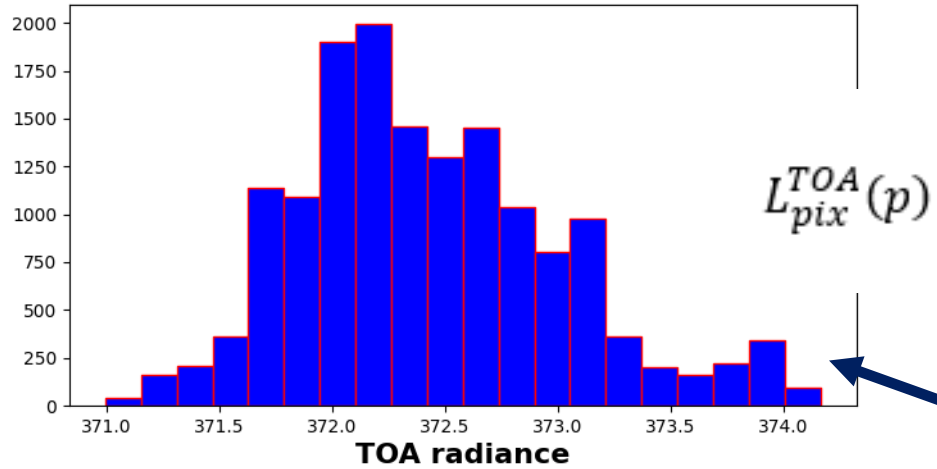
Relative radiance range (%) : B01





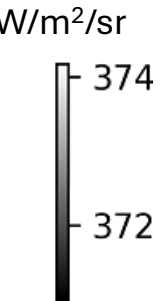
Histogram of TOA radiance over all pixels : B01 snow

TOA radiance: min, avg, max: 371.00 372.43 374.17

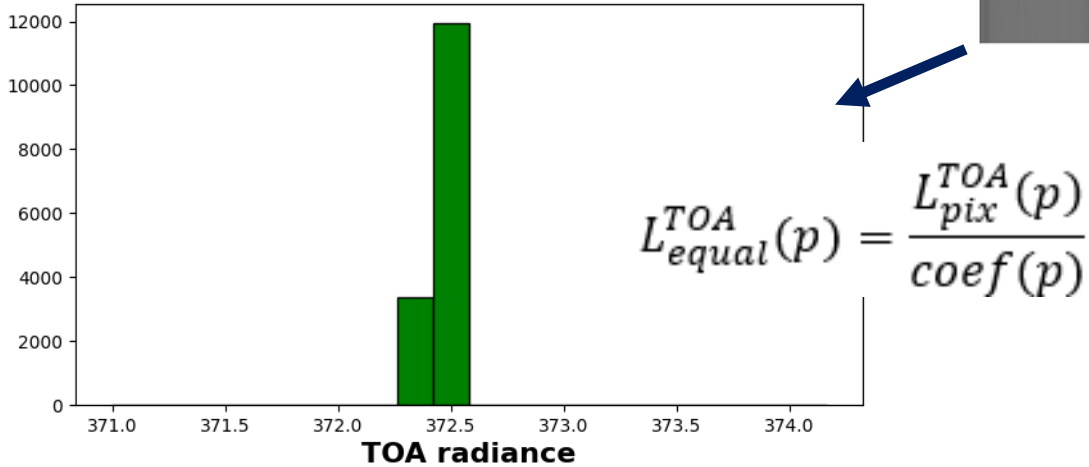


TOA radiance per pixel

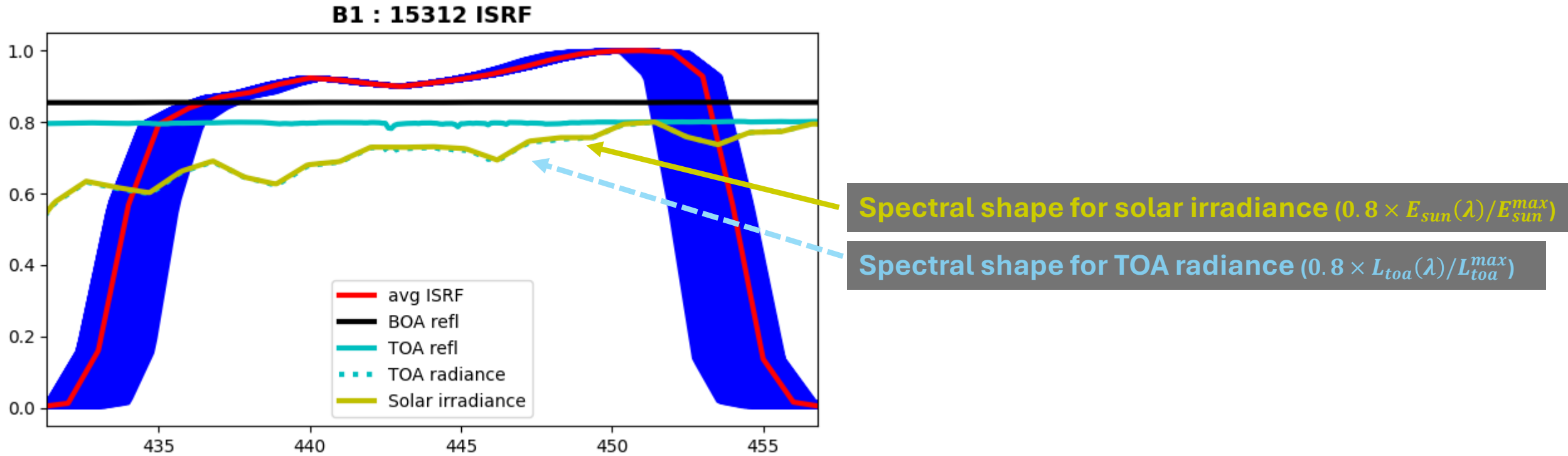
B1 Snow



TOA radiance with equalization: min, avg, max: 372.28 372.43 372.48



❖ Condition of effectiveness of the equalisation coefficients in compensating for the ISRF variation



For scenes with a spectral dependence similar to the sun-diffuser one

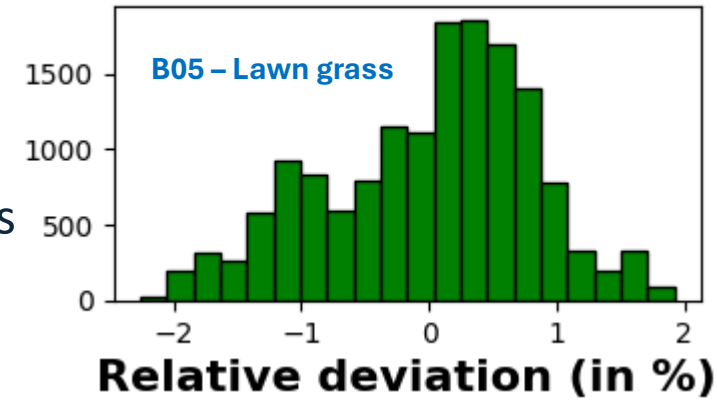
➔ equalisation coefficients are suited to compensate for the ISRF variation

❖ Difference between radiance for ISRF(p) and for the average ISRF

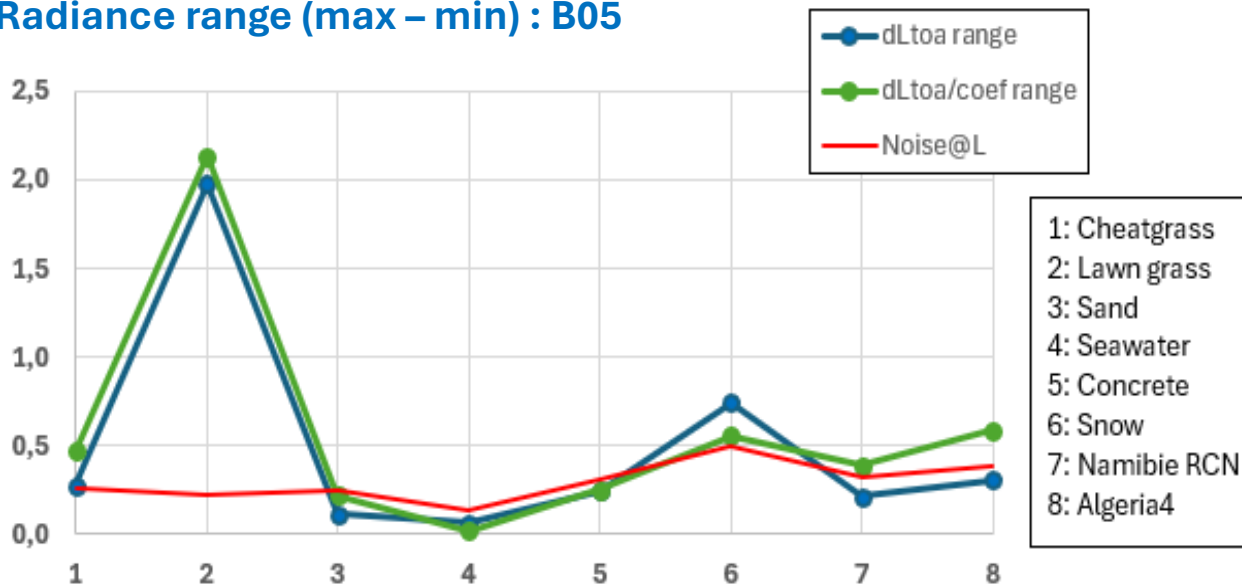
✓ **B05 band (707.1 nm): $\Delta CWL_{max} = 1.0 \text{ nm}$**

- Equalisation increases the radiance dispersion for most of surface types
- Highest impact of ISRF variation : Lawn grass

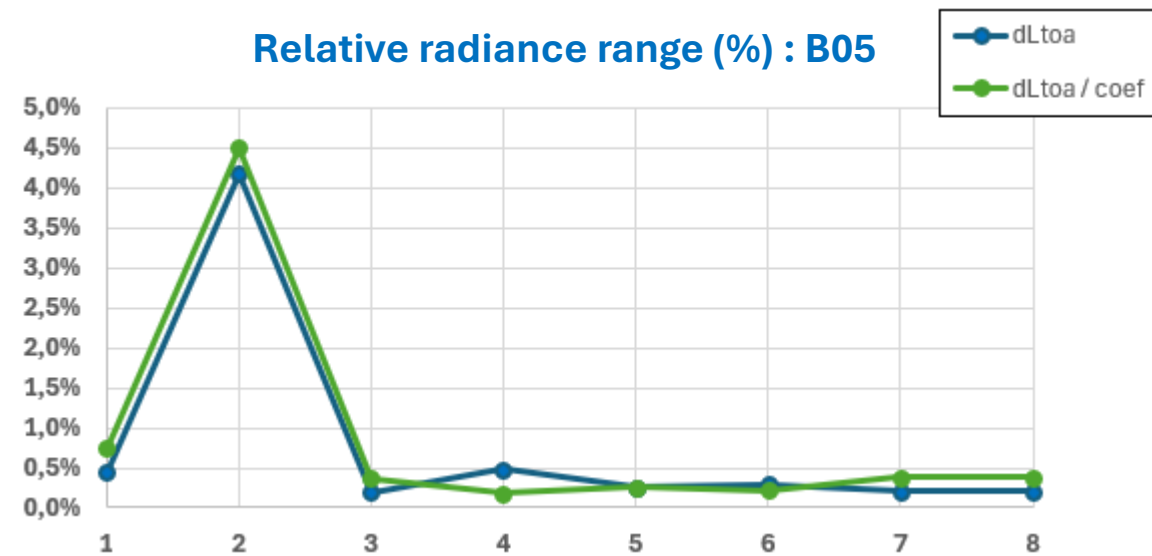
With equal. (%): $\sim -2.43 \quad 0.00 \quad 2.08$



Radiance range (max - min) : B05



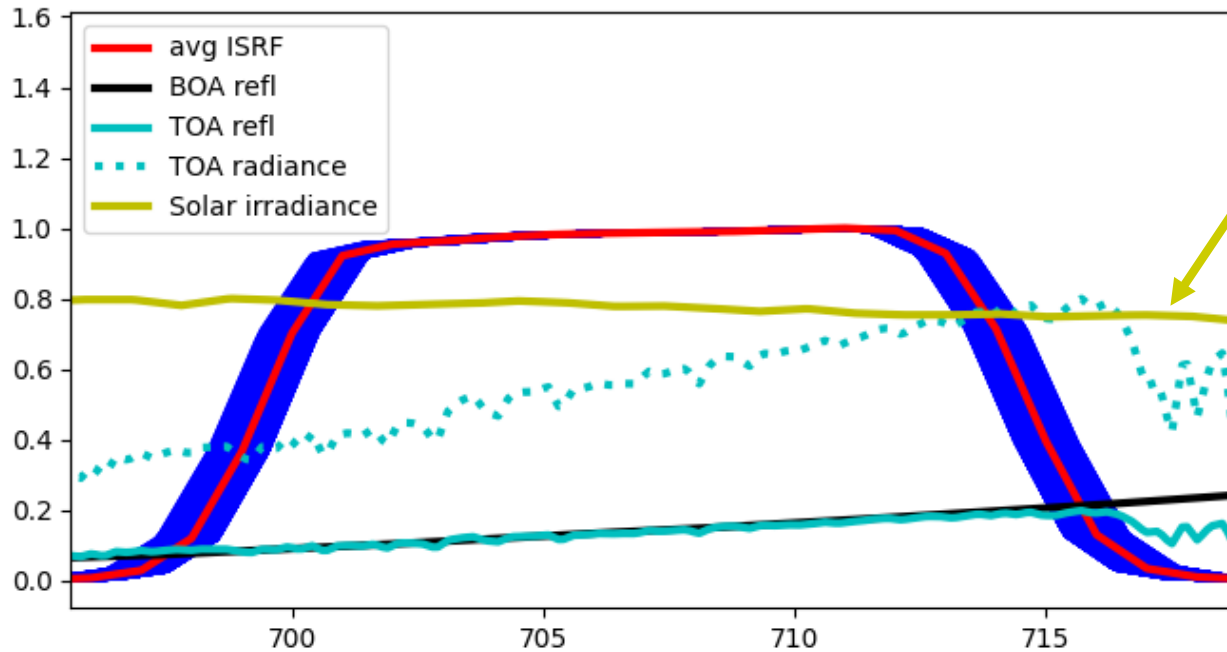
Relative radiance range (%) : B05



❖ B05 / lawn grass :

- ✓ TOA radiance has a fast spectral variation → sensitive to a shift in the spectral band

B5 : 15312 ISRF



Spectral shape for solar irradiance ($0.8 \times E_{sun}(\lambda) / E_{sun}^{max}$)

Spectral shape for TOA radiance ($0.8 \times L_{toa}(\lambda) / L_{toa}^{max}$)

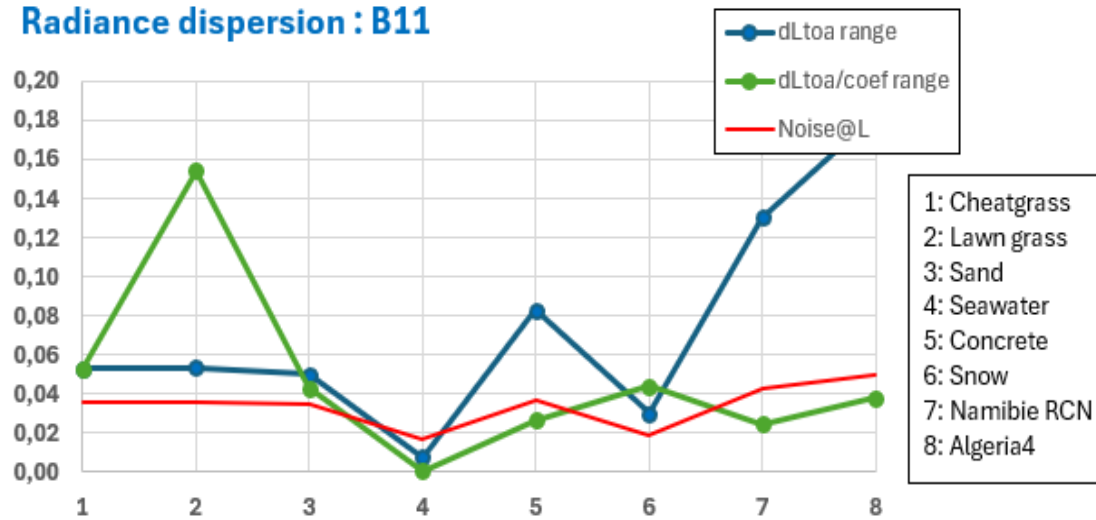
- ✓ For scenes with a spectral dependence different to the sun-diffuser one
→ equalisation coefficients can not compensate for the ISRF variation

❖ Difference between radiance for ISRF(p) and radiance for the average ISRF

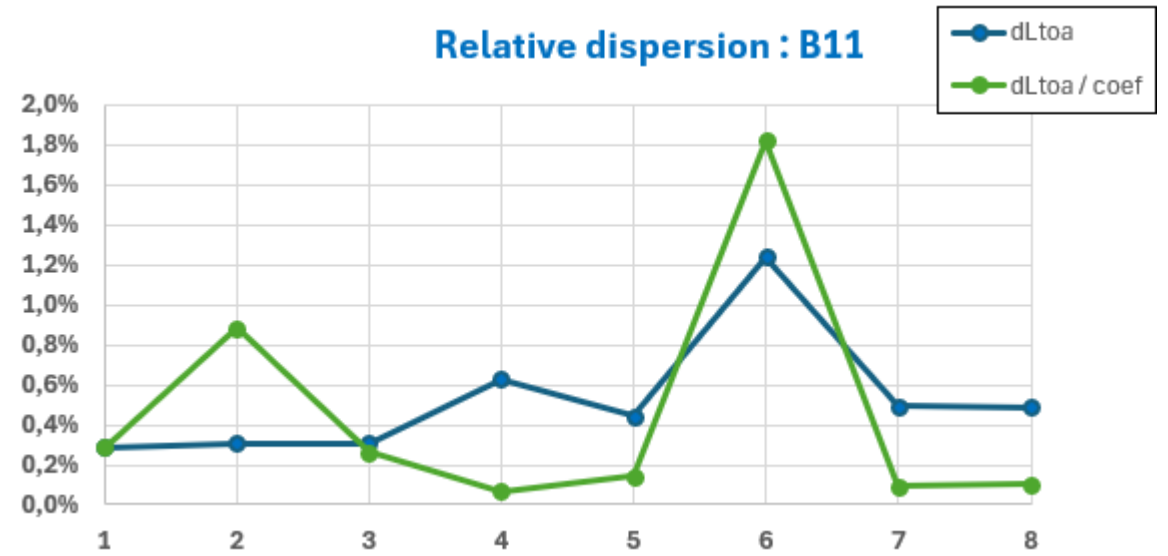
✓ **B11 band (1611.1 nm): $\Delta\text{CWL}_{\text{max}} = 1.0 \text{ nm}$**

- Most contrasted results depending on the surface type : max impact 1.8% over snow
- ISRF part in equalisation coefs :
 - » efficient for certain surfaces
 - » inefficient for other surfaces (grass, snow)

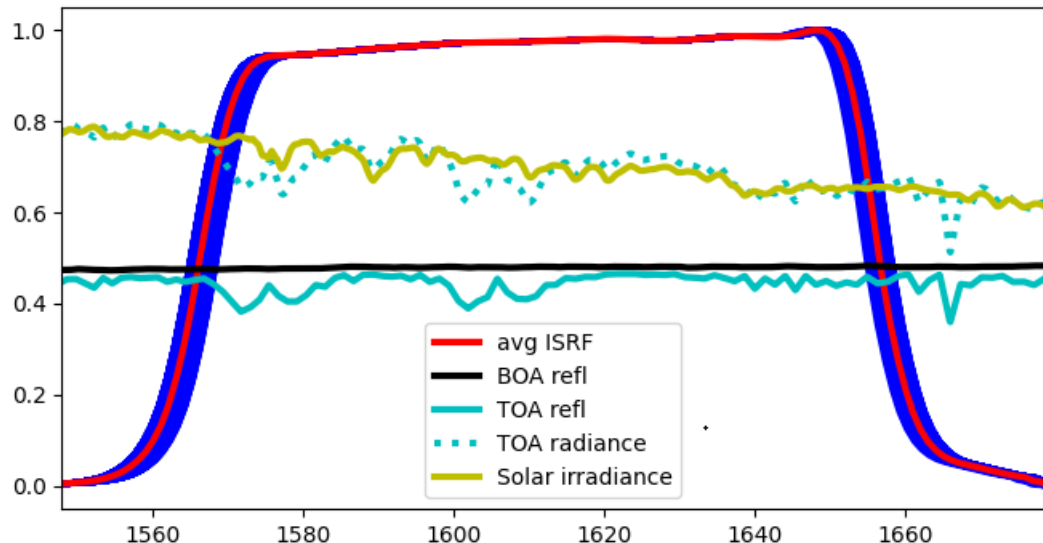
Radiance dispersion : B11



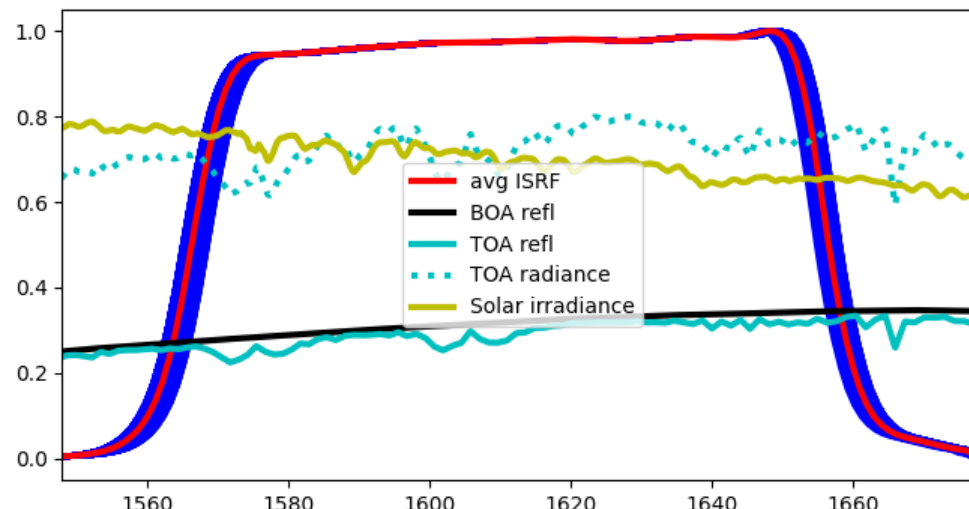
Relative dispersion : B11



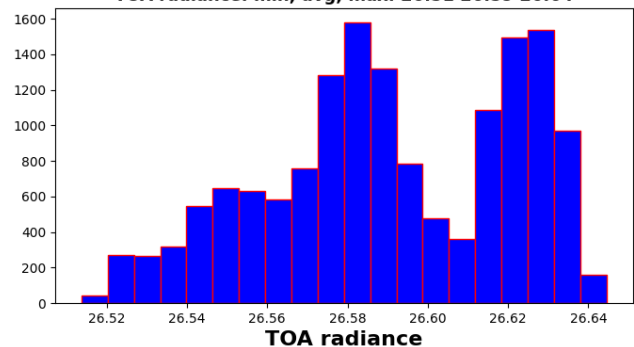
B11 Namibie



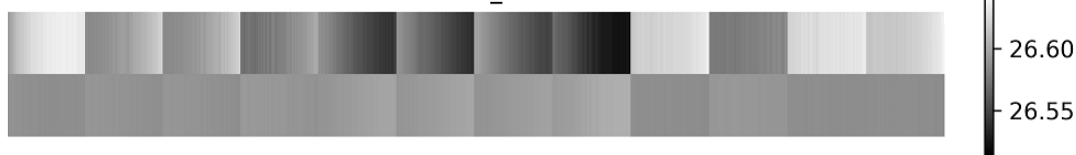
B11 Lawn grass



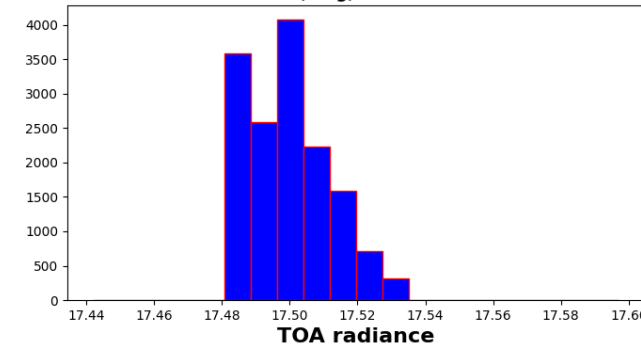
TOA radiance: min, avg, max: 26.51 26.59 26.64



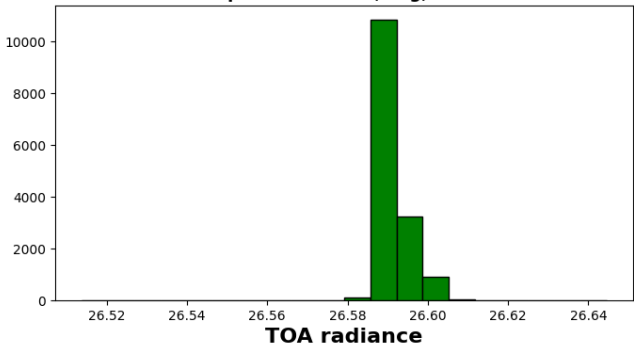
B11 Namibie_RadCalNet



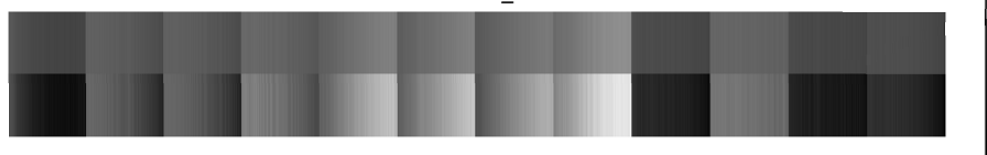
TOA radiance: min, avg, max: 17.48 17.50 17.54



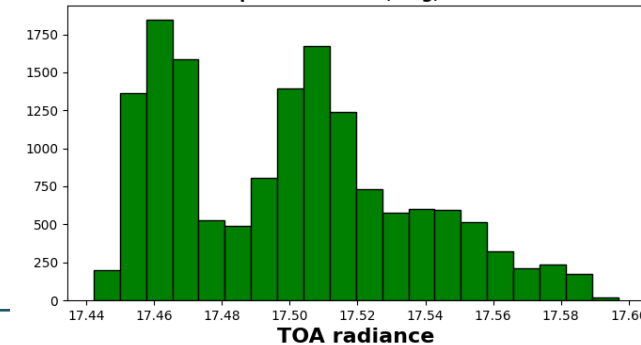
TOA radiance with equalization: min, avg, max: 26.58 26.59 26.61



B11 Lawn_Grass



TOA radiance with equalization: min, avg, max: 17.44 17.50 17.60





Conclusions

- ❖ Most significant impact of ISRF variation:
 - ✓ B05 over lawn grass : ~4.5%
 - ✓ B09 : 5.4%

- ❖ Lowest impact of ISRF variation:
 - ✓ B8A: ~0.2%
 - ✓ B01, B04, B07 : <0.5%
 - ✓ B02, B03 : < 0.6%

- ❖ Maximum impact ~2% for:
 - ✓ B06, B08, B11, B12

	CWL (nm)	Ltoa	Ltoa cor equal.	Surface
B01	443.9	0.9%	0.4%	seawater
B02	488.7	0.7%	0.6%	seawater
B03	560.5	0.7%	0.6%	Lawn grass, Algerie4
B04	666.6	0.3%	0.4%	cheatgrass
B05	707.1	4.2%	4.5%	Lawn grass
B06	741.1	2.2%	2.4%	Lawn grass
B07	785.1	1.0%	0.5%	seawater, snow
B08	843.2	3.4%	2.2%	seawater
B8A	865.9	0.3%	0.2%	cheatgrass
B09	947.8	5.1%	5.4%	All surfaces (except seawater)
B11	1611.1	1.2%	1.8%	snow
B12	2192.3	1.4%	2.1%	snow



Conclusions

- ❖ Equalisation can trend to compensate for the ISRF variation, but can also increase its impact on measurements
 - ✓ Bands taking benefit of the equalisation to compensate for the ISRF variation: **B01, B02, B03** (except over Namibie and Algeria4 calib. sites), **B07, B08, B8A, B12** (except snow).
 - ✓ Increase of the radiance dispersion by the impact of ISRF variation in equalisation coefficients for: bands **B04** (except over lawn grass and seawater), **B05** (except over snow), **B06** and **B09**



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Optical Mission Performance Cluster

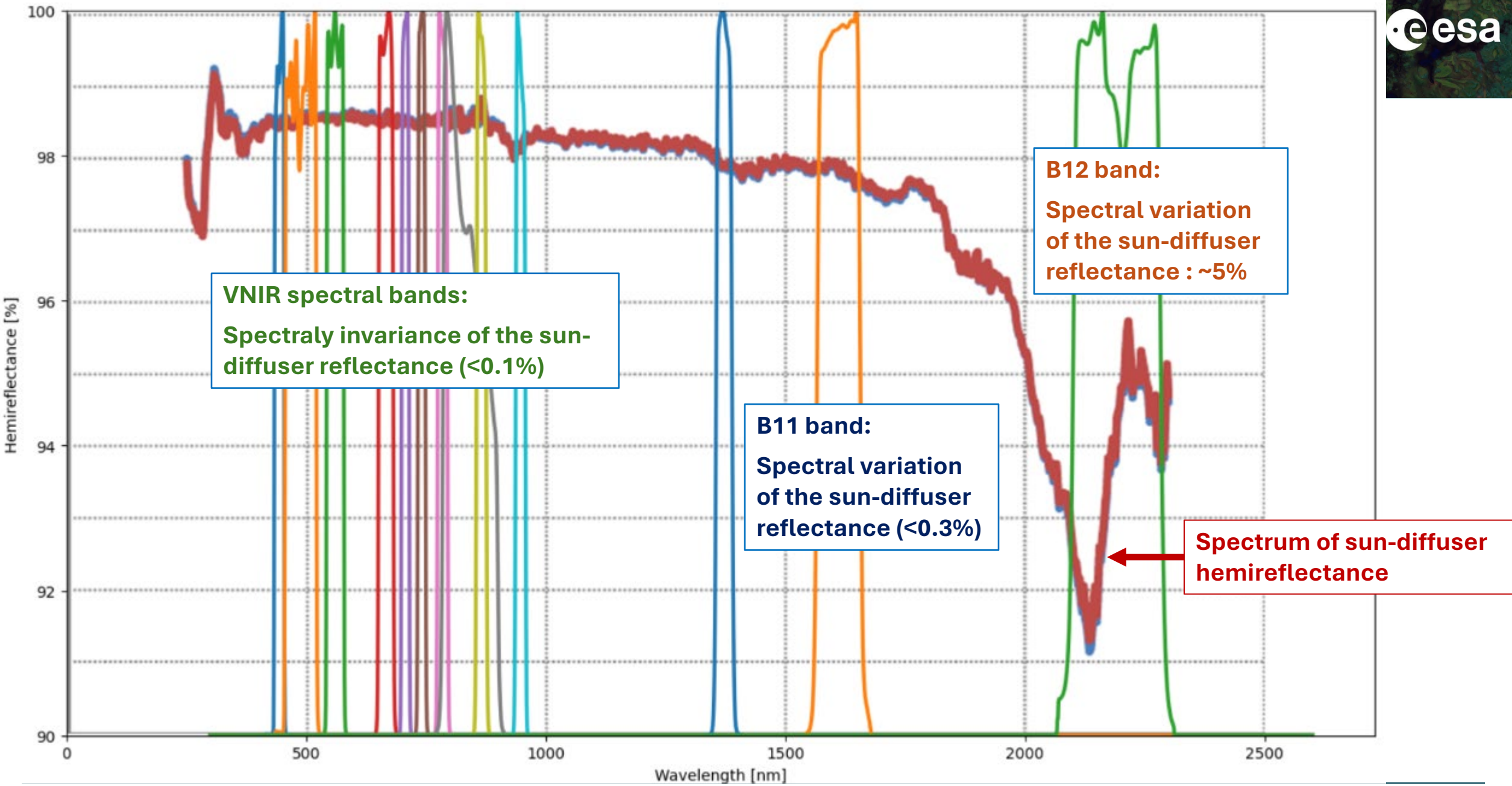
Funded by the EU and ESA



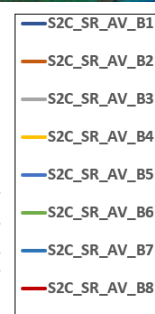
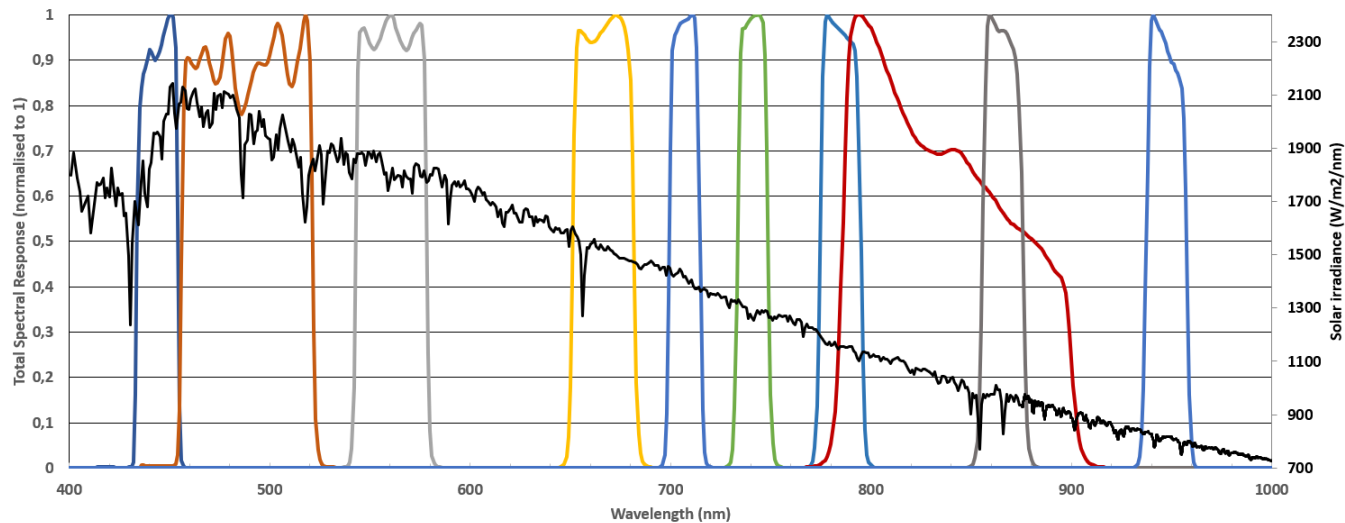
European Union



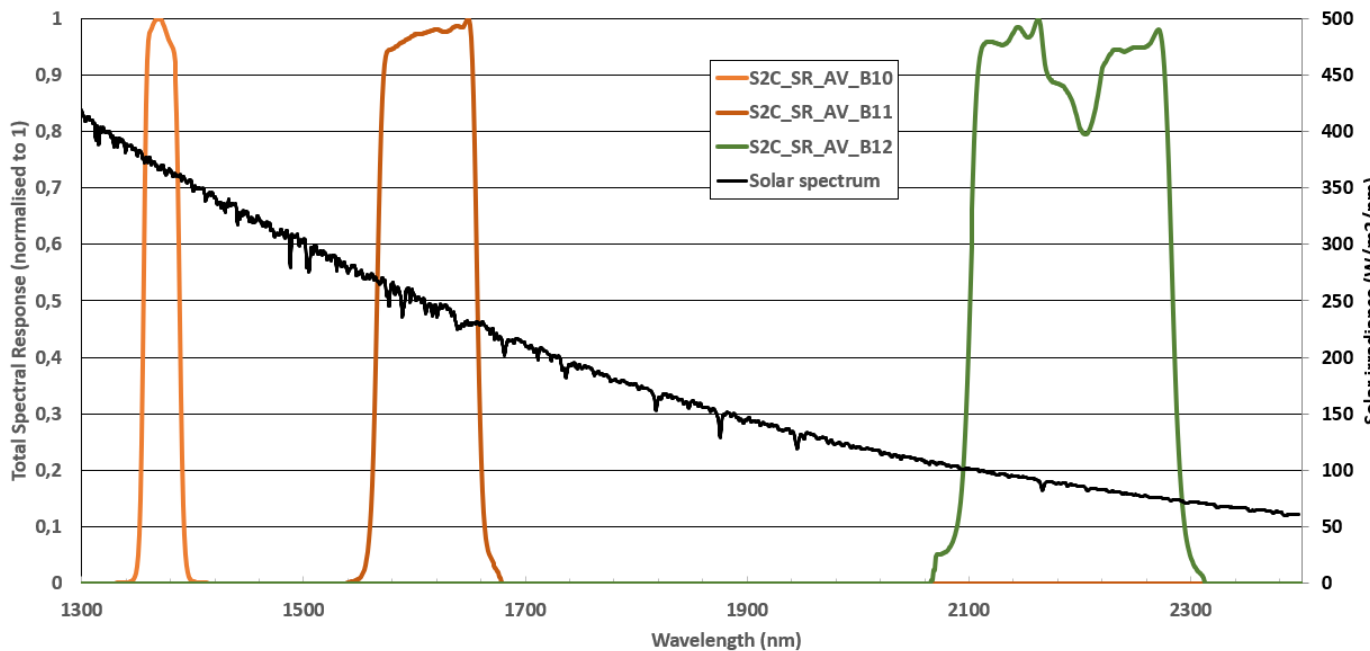
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S2A, S2B & S2C MSI Spectral Response Average - VNIR



S2C MSI Spectral Response Average - SWIR



Solar irradiance variation:

- ❖ >> sun-diffuser spectral variation for VNIR bands
 - ❖ ~10% in the B11 spectral band
>> 0.3% spectral variation for sun-diffuser
 - ❖ ~30% in the B12 spectral band
>> 5% spectral variation for sun-diffuser
- ➔ Invariance of the sun-diffuser spectrum is less efficient for B12