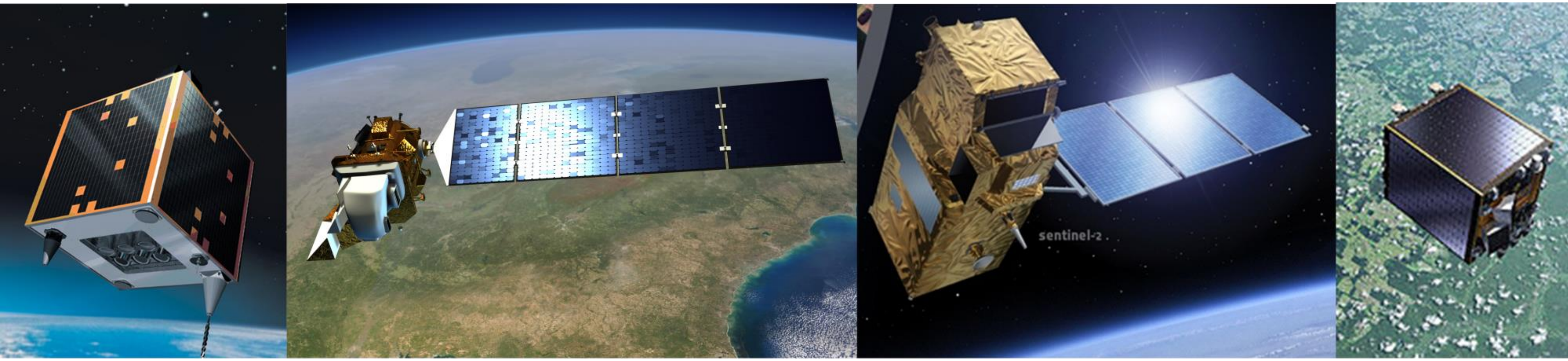


THE BELHARMONY APPROACH FOR HARMONIZATION OF PROBA-V, DEIMOS-1 LANDSAT-8 AND SENTINEL-2 TIMESERIES

Sindy Sterckx[1,*], Else Swinnen[1] ,Erwin Wolters[1] Charlotte Wirion[2],Boud Verbeiren[2], Cristiana Bassani[3]

[1]VITO (Belgium),[2] VUB (Belgium), [3] CNR IIA (Italy)

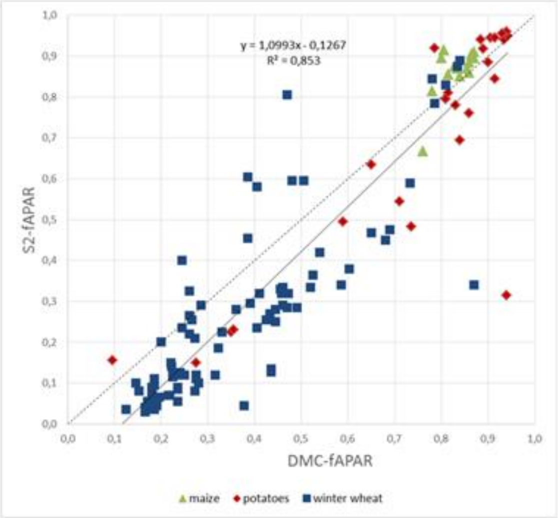
*

BELHARMONY OVERALL OBJECTIVE

- To assess and improve the consistency of multi-sensor high resolution time series. (HARMONY)
- Landsat-8, Sentinel-2, PROBA-V (central camera) and Deimos-1/DMC
- How ?

  Bottom-up approach

  (from L1 to L2 to L3)

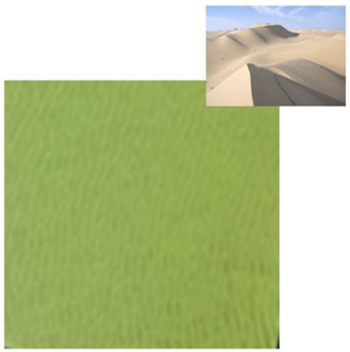


BELHARMONY SCIENTIFIC QUESTIONS

1. Are the the L1 TOA data consistent ?

Medium to high radiances

Inter-comparison over the Libya-4 PICS desert site following the OSCAR* desert approach



Bias Assessment over instrument RadCalNet sites (Land Equipped Sites (LIS))

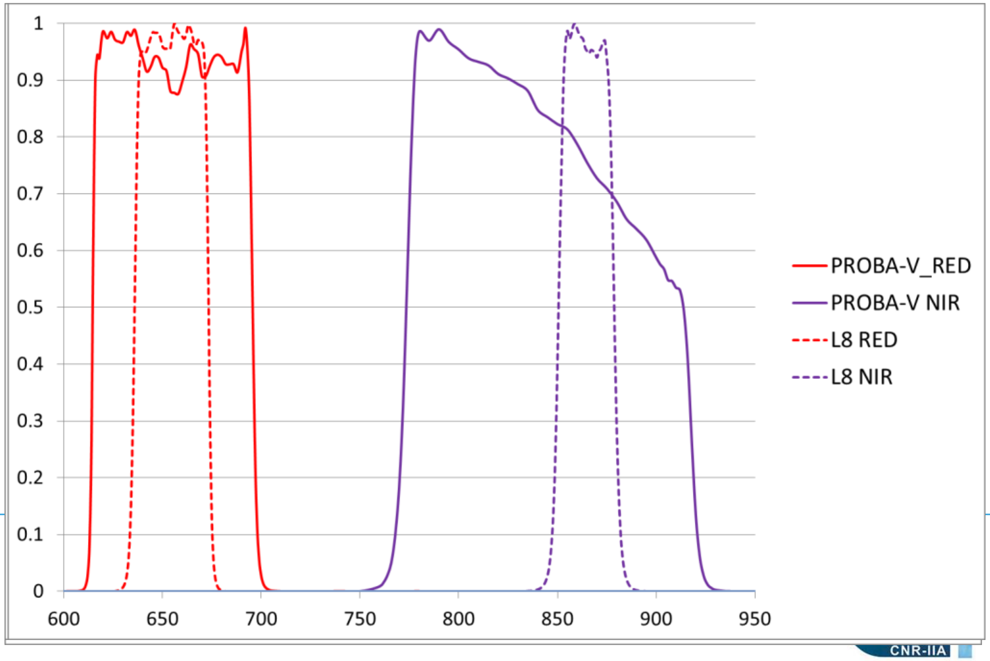
*OSCAR (Optical Sensor Calibration with simulated Radiances). Govaerts, Y., S. Sterckx, and S. Adriaensen (2013). Use of simulated reflectances over bright desert target as an absolute calibration reference. Remote Sensing Letters, , Vol. 4: 6, 523-531.

Low radiances

BELHARMONY SCIENTIFIC QUESTIONS

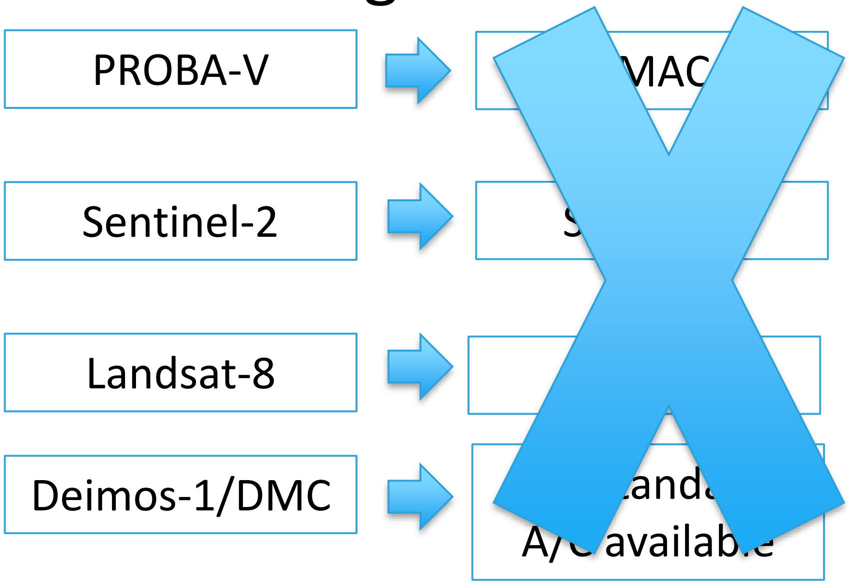
1. Are the the L1 data consistent ?
2. What is the impact of intrinsic differences in the RSRF of the different sensors ?

- Can BELHARMONY through the introduction of band or index dependent spectral adjustment functions correct for this ?



BELHARMONY SCIENTIFIC QUESTIONS

1. Does there exist a bias in the L1 data ?
2. What is the impact of intrinsic differences in the RSRF of the different sensors ?
3. Can differences in L2 and L3 data be reduced through the use of a common processing chain ?



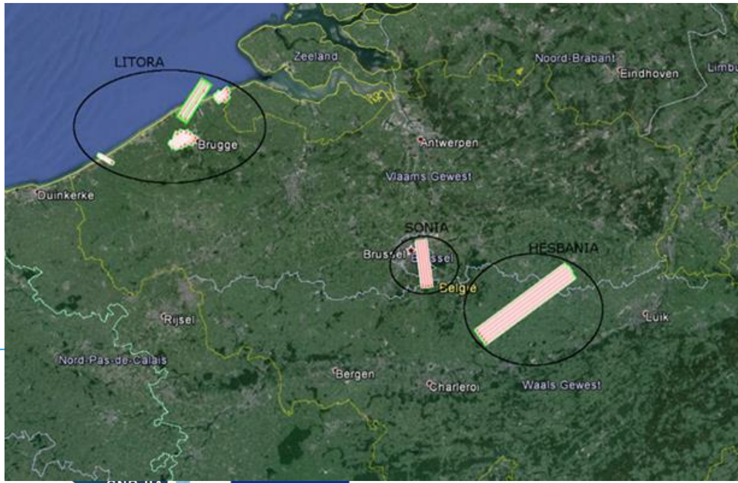
iCOR
atmospheric image correction for land and water

De Keukelaere et al. (2018)

1. Does there exist a bias in the L1 data ?
2. What is the impact of intrinsic differences in the RSRF of the different sensors ?
3. Can differences in L2 and L3 data be reduced through the use of a common processing chain ?
4. What is impact of all these harmonization measures on the consistency of the multi-sensor L2/L3 time series?

=> BELHARMONY APPROACH:

BELAIR CASE STUDIES



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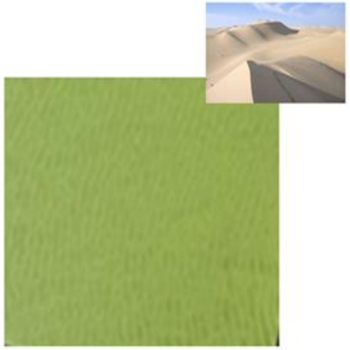

Bias Assessment over instrument RadCalNet sites (Land Equipped Sites (LIS))

Open Access Article

Radiometric Top-of-Atmosphere Reflectance Consistency Assessment for Landsat 8/OLI, Sentinel-2/MSI, PROBA-V, and DEIMOS-1 over Libya-4 and RadCalNet Calibration Sites

by Sindy Sterckx * and Erwin Wolters

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Remote Sens. **2019**, *11*(19), 2253; https://doi.org/10.3390/rs11192253

Received: 19 August 2019 / Revised: 24 September 2019 / Accepted: 25 September 2019 / Published: 27 September 2019

Low radiances

Open Access Article

Calibration of Satellite Low Radiance by AERONET-OC Products and 6SV Model

by Cristiana Bassani [1,*] and Sindy Sterckx [2]

[1] National Research Council-Institute of Atmospheric Pollution Research (CNR-IIA), Via Salaria Km 29.3, C.P. 10, 00015 Rome, Italy
[2] Flemish Institute for Technological Research (VITO)—Remote Sensing Unit, Boeretang 200, 2400 Mol, Belgium
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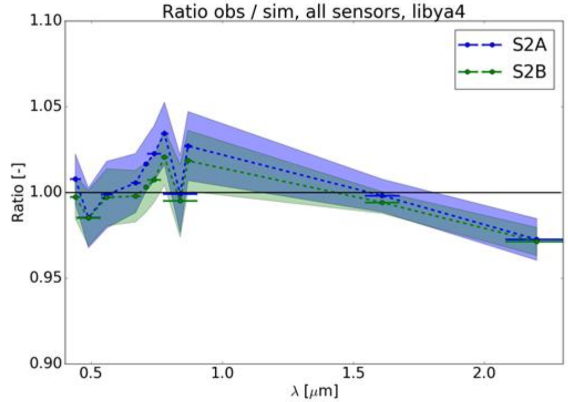
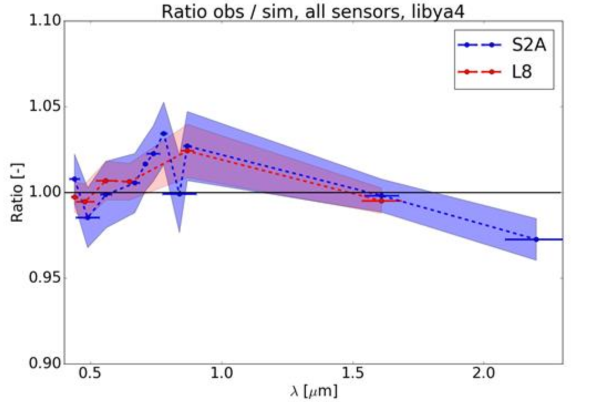
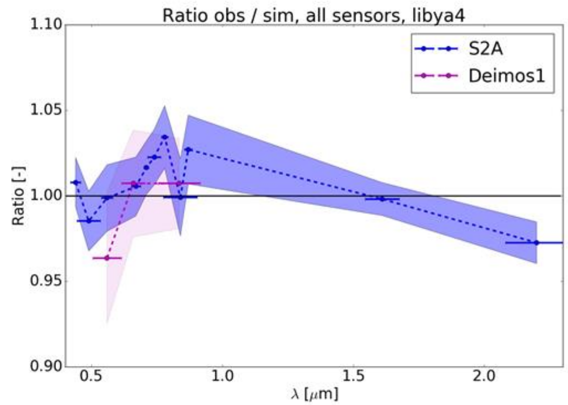
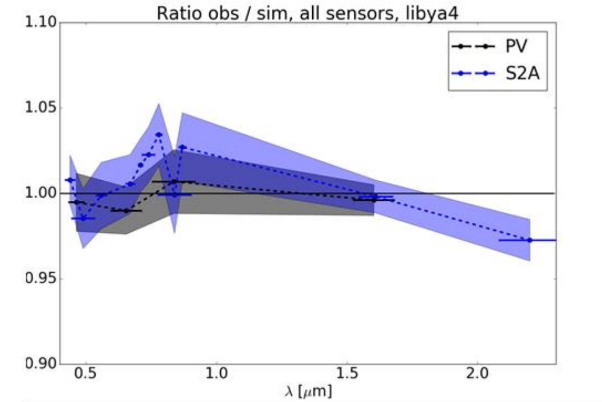
Received: 25 January 2021 / Revised: 13 February 2021 / Accepted: 16 February 2021 / Published: 20 February 2021

RESULTS : LIBYA-4 DESERT









RADCALNET

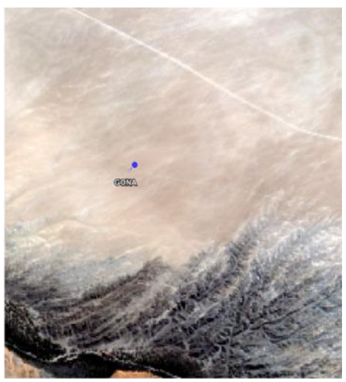
RadcalNet portal

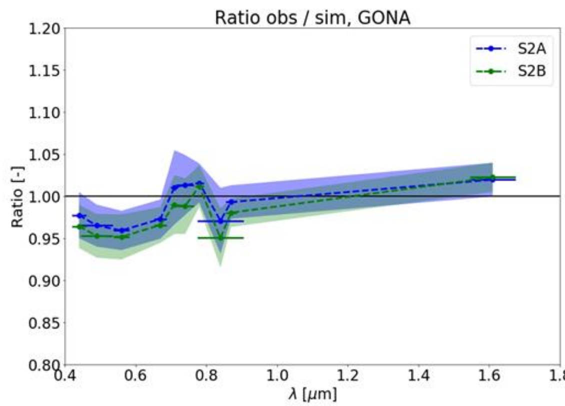
TOA reflectances:

- **Nadir**
- **Max. time diff 30 min**
- **Spectral resampling of RadCalNet TOA reflectances (at 10 nm)**

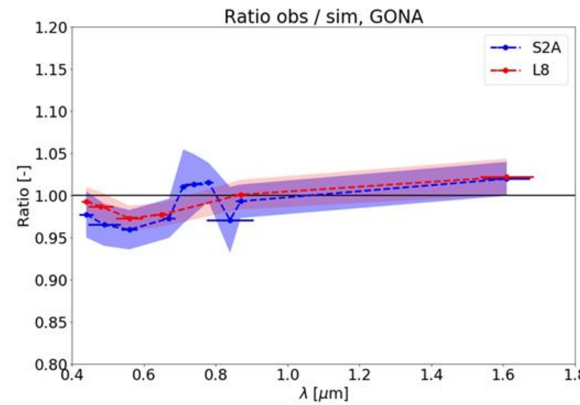
Sensor	LCFR	RVUS	GONA	Total
Sentinel-2A	32	14	27	73
Sentinel-2B	20	8	22	50
Landsat 8	24	6	14	44
PROBA-V	103	28	42	173
Deimos1	4	7	0	11

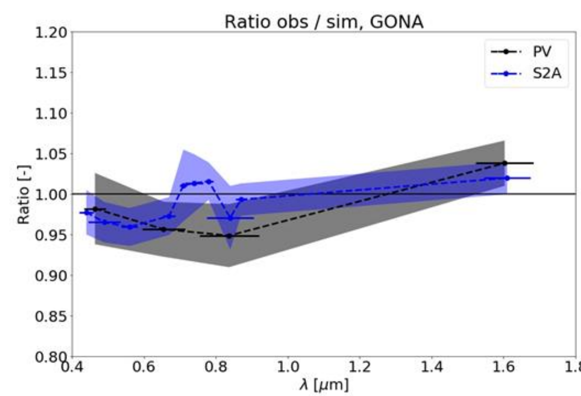
RESULTS : GOBABEB RADCALNET



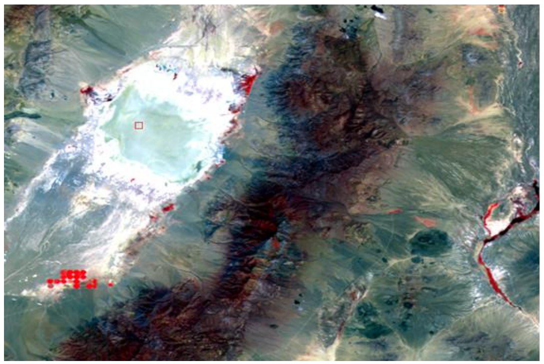


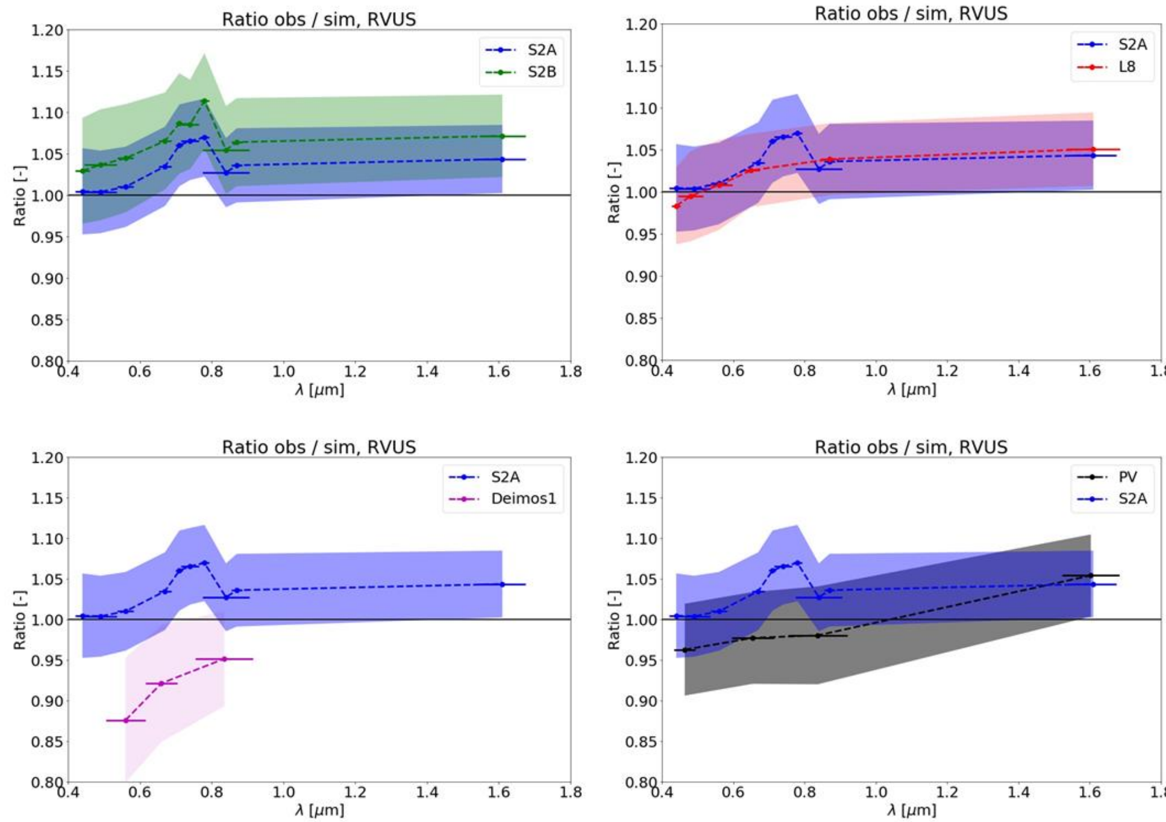
No Deimos1 data available for GONA





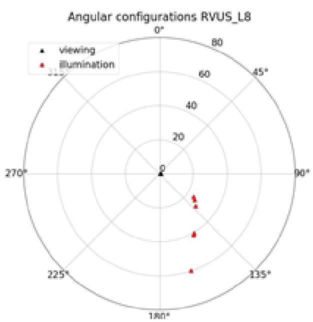
RESULTS : RAILROAD RADCALNET



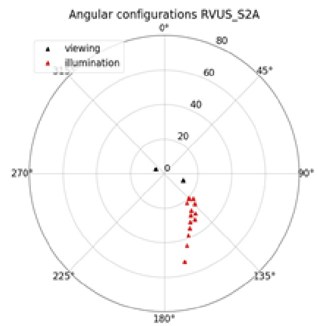


BRDF effects RVUS, RED

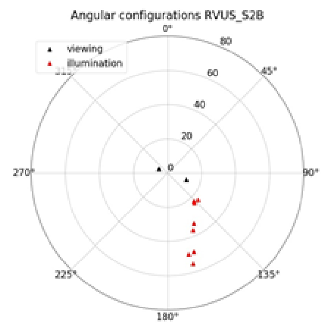
L8



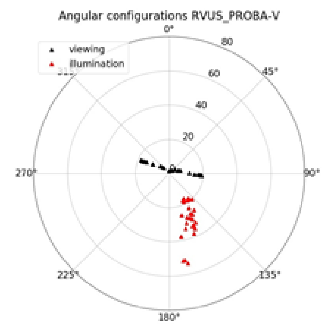
S2A



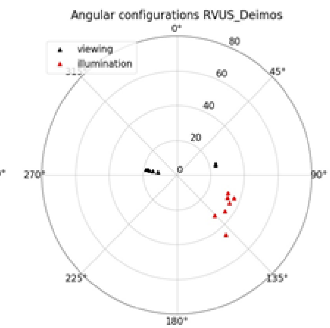
S2B



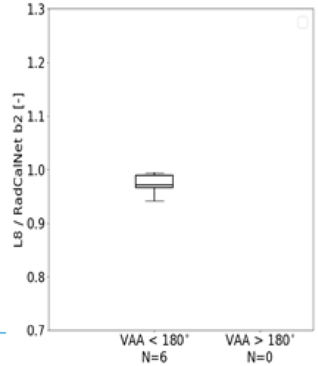
PV



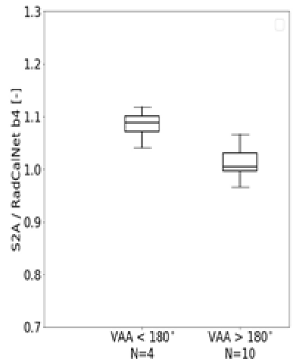
D1



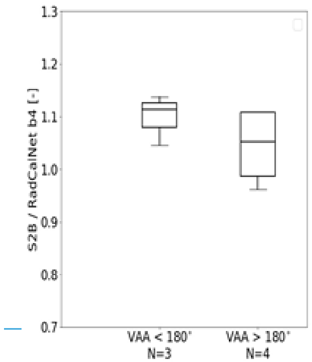
L8 B2



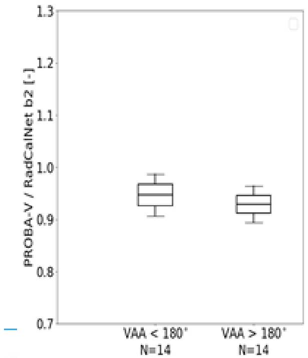
S2A B4



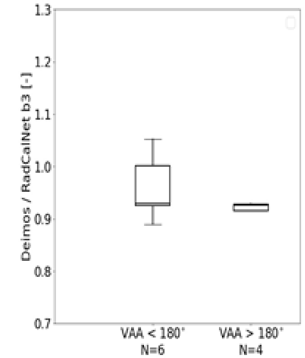
S2B B4



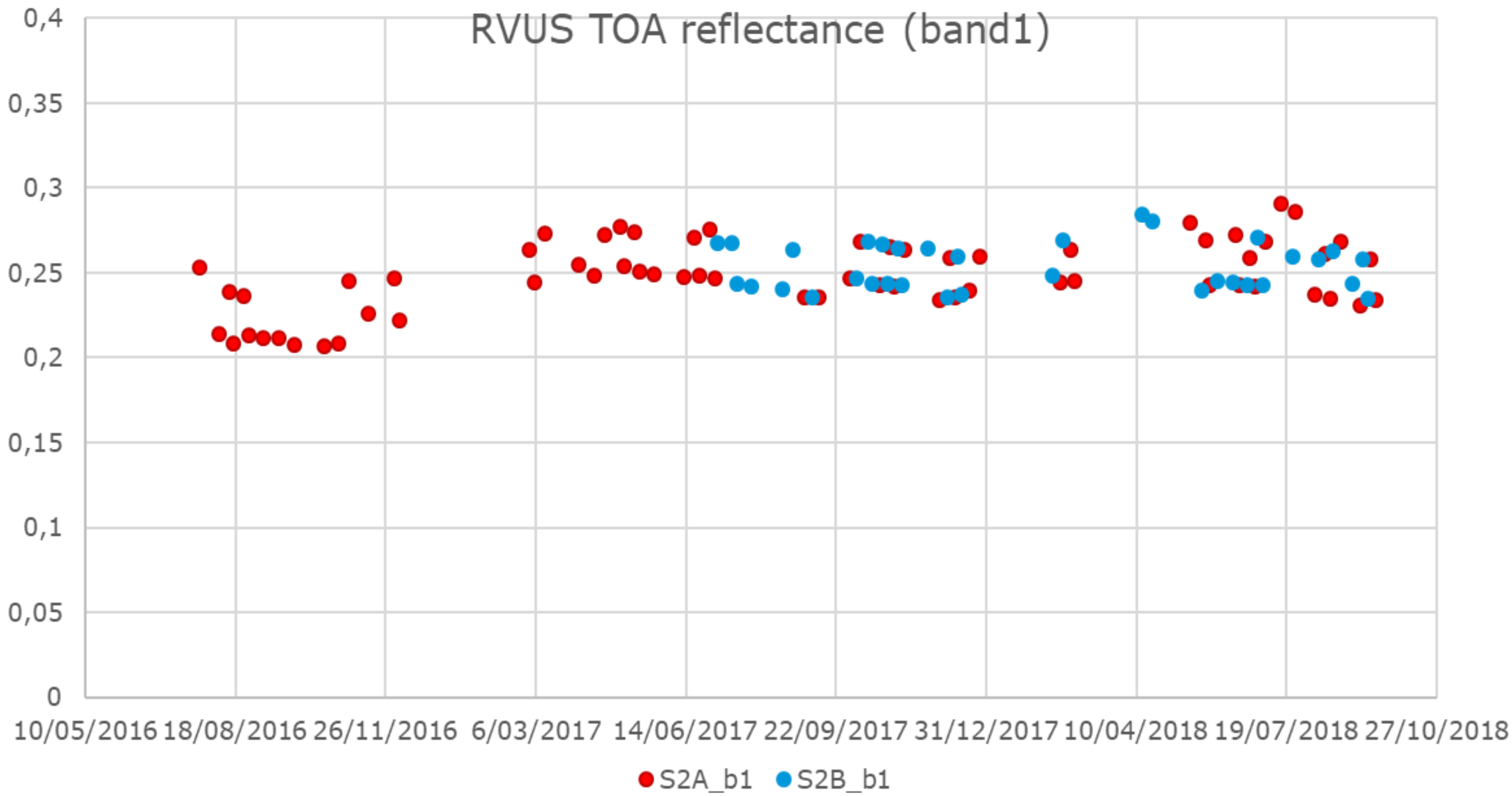
PV B2



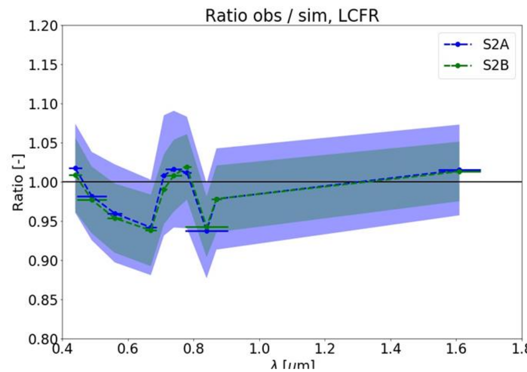
D1 B3

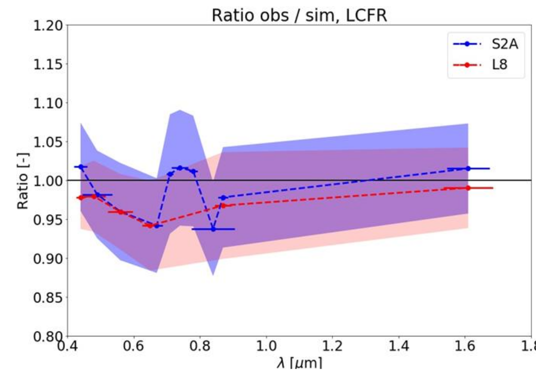


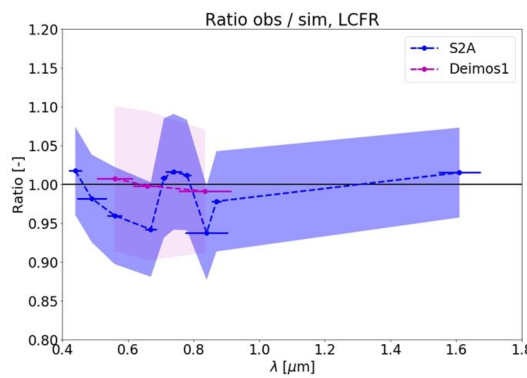
RESULTS : RAILROAD RADCALNET

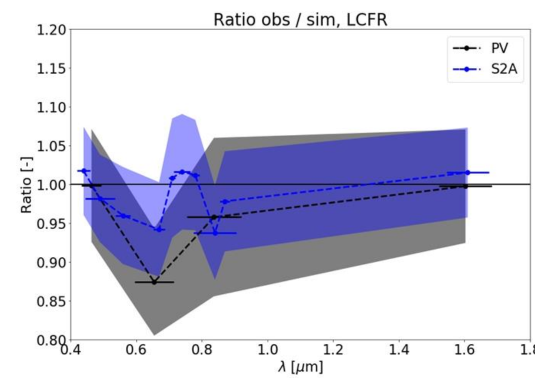


RESULTS : LA CRAU RADCALNET

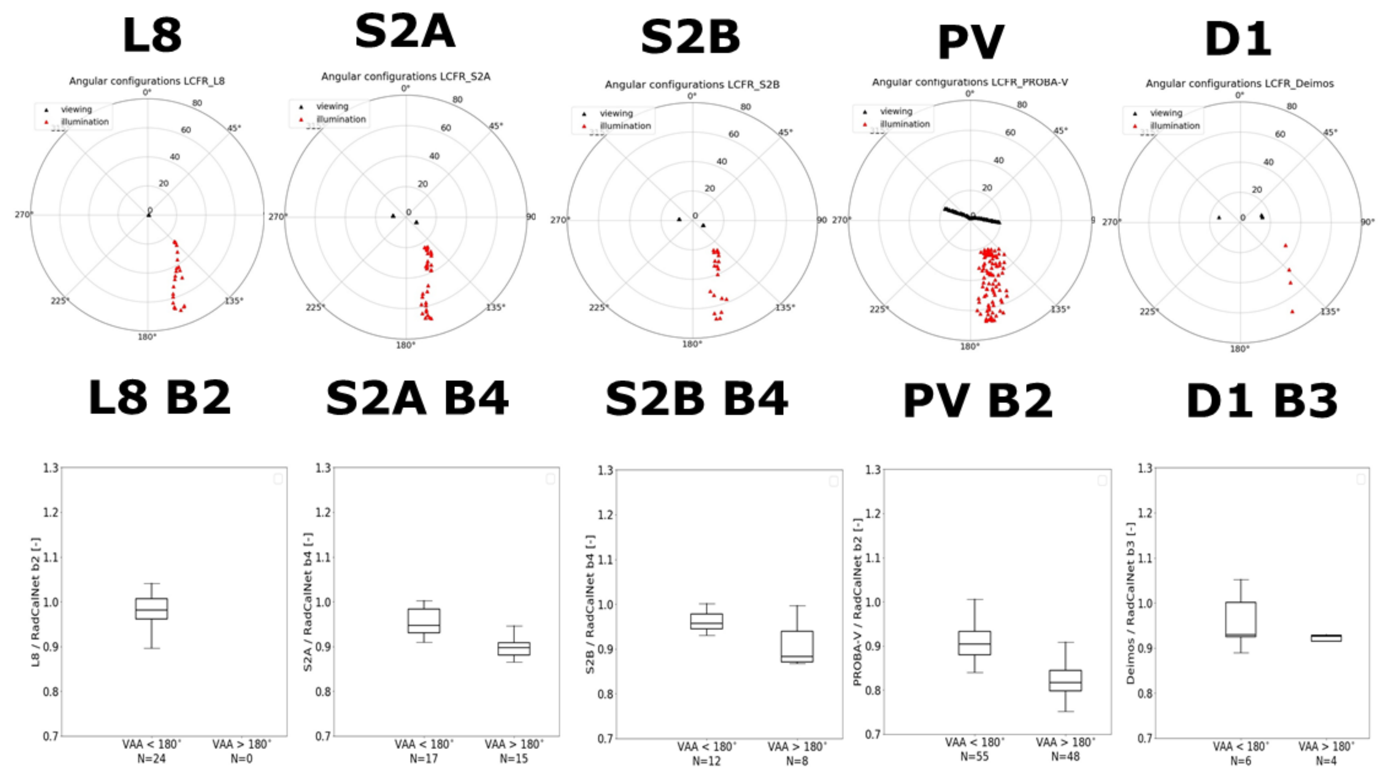








Brdf effects LCFR, RED



BELHARMONY RESULTS

Does there exist a bias in the L1 data ?

S2 band	S2 cwv	S2A ratio	% dif S2B vs S2A	LS8 band	LS8 cwv	% dif LS8 vs S2A	Deimos1 band	Deimos-1 cwv	% dif D-1 vs S2A	PV band	PV cwv	% dif PV vs S2A
1	443	1.008	−1.05%	CA	443	−1.05%				Blue	460	−1.30%
2	490	0.985	−0.03%	Blue	492	0.94%					460	0.97%
3	560	0.999	−0.16%	Green	561	0.82%	Green	549	−3.5%			
4	665	1.005	−0.76%	Red	654	0.08%	Red	679	0.2%	Red	658	−1.55%
5	705	1.016	−1.32%									
6	740	1.023	−1.49%									
7	783	1.034	−1.35%									
8	842	0.999	−0.40%				NIR	803	0.8%	NIR	834	0.78%
8A	865	1.027	−0.84%	NR	865	−0.28%						
9	945	NA	NA									
10	1375	NA	NA	Cirrus	1373	NA						
11	1610	0.998	−0.40%	SWIR1	1610	−0.30%				SWIR	1610	−0.21%
12	2190	0.973	−0.12%	SWIR2	2200	0.28%						

Open Access Article

Radiometric Top-of-Atmosphere Reflectance Consistency Assessment for Landsat 8/OLI, Sentinel-2/MSI, PROBA-V, and DEIMOS-1 over Libya-4 and RadCalNet Calibration Sites

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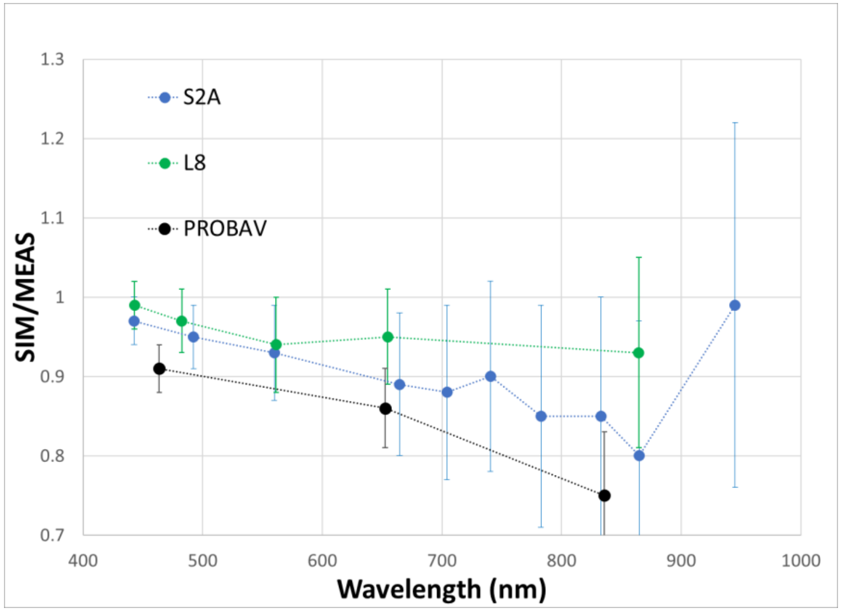
- Relative differences between sensors small Lybia 4 (< ±1.5%) and Gobabeb (< ±2.5%)
- Deimos 1 green band larger differences 3.5%
- Differences between S2A and S2B of the same magnitude as differences observed between Sentinel-2A and the other sensors.
- S2A possibly slightly brighter than S2B, but within uncertainty range of reference methods

BELHARMONY RESULTS

Does there exist a bias in the L1 data ?



1. AERONET-OC products Lev 2.0
2. Configuration of sensor acquisition

6SV

Hyperspectral TOA simulated reflectance

Convolution to RSR

REF == Simulated TOA signal

Screenings

GAINS=REF/MEAS

Open Access | Article

Calibration of Satellite Low Radiance by AERONET-OC Products and 6SV Model

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BELHARMONY RESULTS

Spectral correction functions derivation

1. **Generate simulations of vegetation and mixtures with different background**
   → Coupled Soil-Leaf-Canopy (SLC) RTM

BELHARMONY RESULTS

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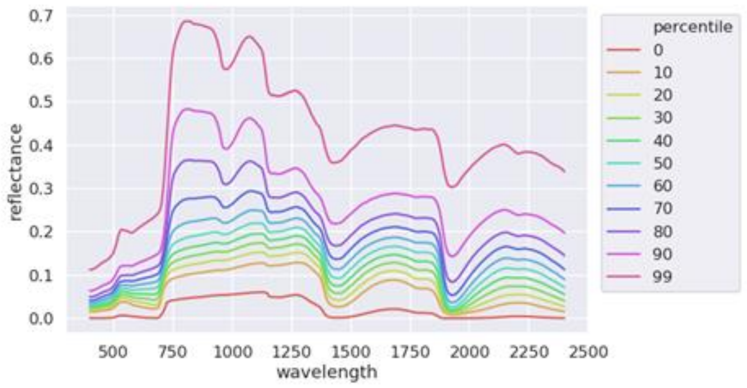
2. **Add man-made and water spectra**
   → Spectral library + ASD measurements



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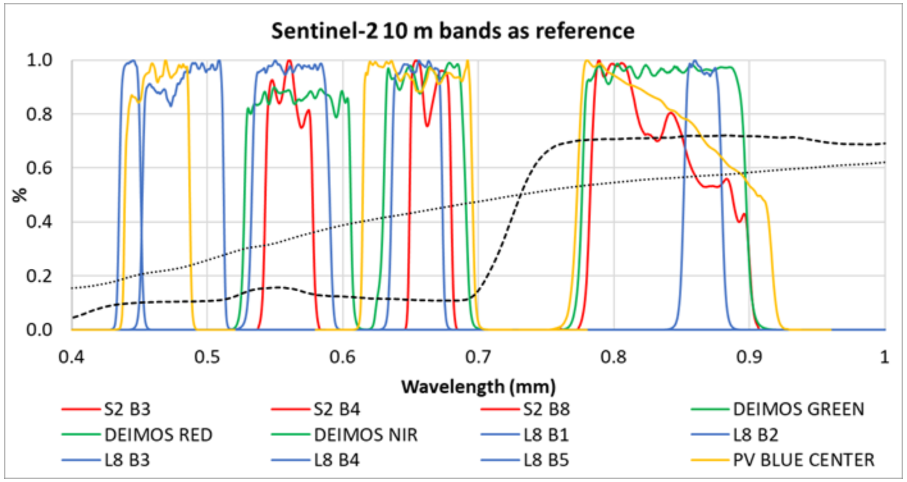

BELHARMONY RESULTS

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3. **Calculate sensor-specific responses using RSRFs**

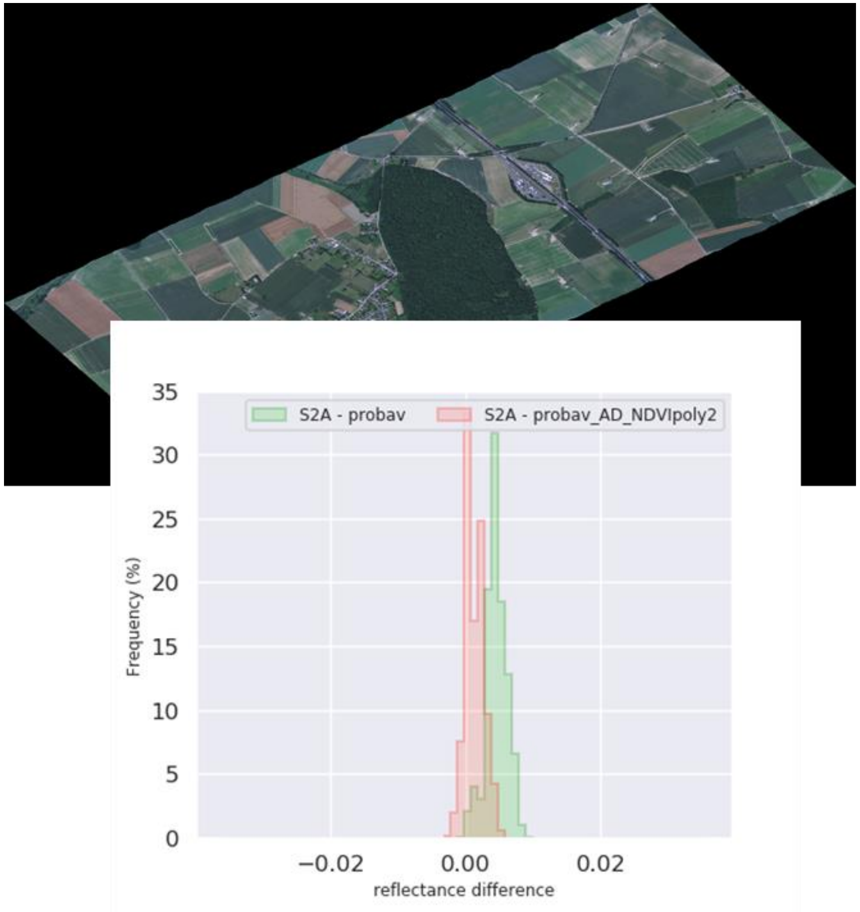
4. **Estimate correction functions per band**

Different models were explored for each band

- Linear model
  - $\bar{\rho}_{\lambda,ref} = a + b \cdot \bar{\rho}_{\lambda,tar}$
- Multi-linear regression models
  - $\bar{\rho}_{\lambda,(red,nir),ref} = \beta_1 \bar{\rho}_{red,tar} + \beta_2 \bar{\rho}_{nir,tar} + \beta_3 NDVI + \beta_3 NDVI^2 + \epsilon$
  - $\bar{\rho}_{\lambda,(g,red,nir),ref} = \beta_1 \bar{\rho}_{(g,red),tar} + \beta_2 \bar{\rho}_{nir,tar} + \beta_3 (\bar{\rho}_{(g,red),tar} \cdot \bar{\rho}_{nir,tar}) + \beta_4 (\bar{\rho}_{(g,red),tar})^2 + \beta_5 (\bar{\rho}_{(nir),tar})^2 + \epsilon$
- Quadratic model of the relative difference in function of the NDVI
  - $SBAF = \frac{\bar{\rho}_{\lambda,ref}}{\bar{\rho}_{\lambda,tar}} = a + b \cdot NDVI + c \cdot NDVI^2$
  - $abs.diff = a + b \cdot NDVI + c \cdot NDVI^2$
  - $rel.diff = a + b \cdot NDVI + c \cdot NDVI^2$
- Exponential function of the SBAF, AD, RD in function of the NDVI
  - $SBAF = a \cdot e^{b \cdot NDVI} + c \cdot e^{d \cdot NDVI}$
  - $AD = a \cdot e^{b \cdot NDVI} + c \cdot e^{d \cdot NDVI}$
  - $RD = a \cdot e^{b \cdot NDVI} + c \cdot e^{d \cdot NDVI}$

Spectral correction functions derivation

1. **Generate simulations of vegetation and mixtures with different background**
   → Coupled Soil-Leaf-Canopy (SLC) RTM
2. **Add man-made and water spectra**
   → Spectral library + ASD measurements
3. **Calculate sensor-specific responses using RSRFs**
4. **Estimate correction functions per band**
5. **Validate the correction functions**



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4. **Estimate correction functions per band**
5. **Validate the correction functions**

Final spectral correction functions

S2A – Landat8

Corresponding Band	Input	Function	Order	Remark
B3	SBAF	NDVIpoly	2	
B4	SBAF	NDVIpoly	3	
B8	-	-	-	No correction possible
B8A	-	-	-	Original bands sufficiently similar
B11	AD	NDVI2exp	-	
B12	refl	Qmultilin	-	

S2A – Deimos1

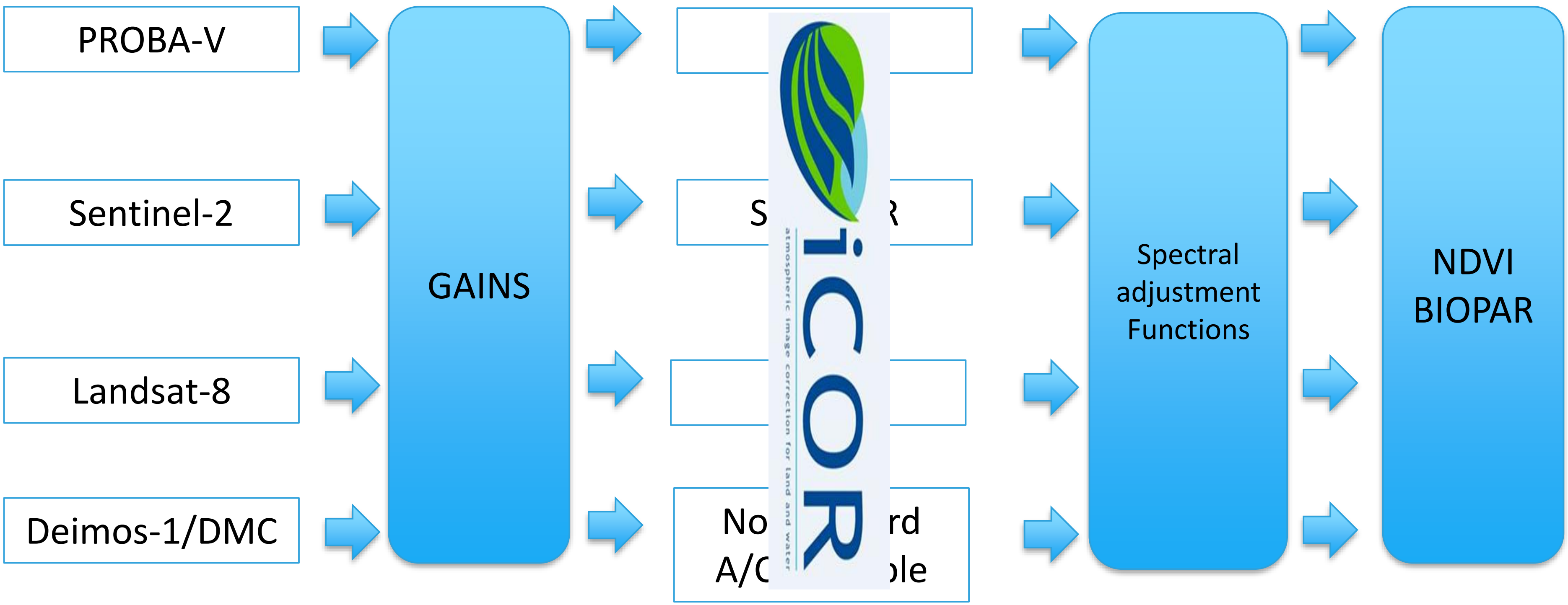
Corresponding Band	Input	Function	Order	Remark
B3	SBAF	NDVIpoly	2	
B4	SBAF	NDVIpoly	3	
B8	-	-	-	Original bands sufficiently similar
B8A	SBAF	NDVI2exp	-	Correction not very effective: optional

S2A – Proba-V

Corresponding Band	Input	Function	Order	Remark
B4	SBAF	NDVIpoly	2	
B8	SBAF	NDVI2exp	-	Small improvement
B8A	-	-	-	No correction possible
B11	AD	NDVIpoly	2	

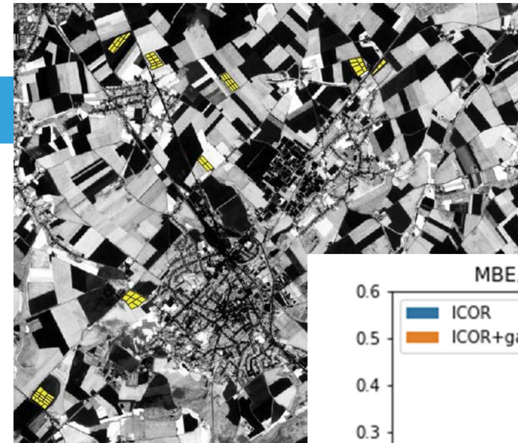
BELHARMONY RESULTS

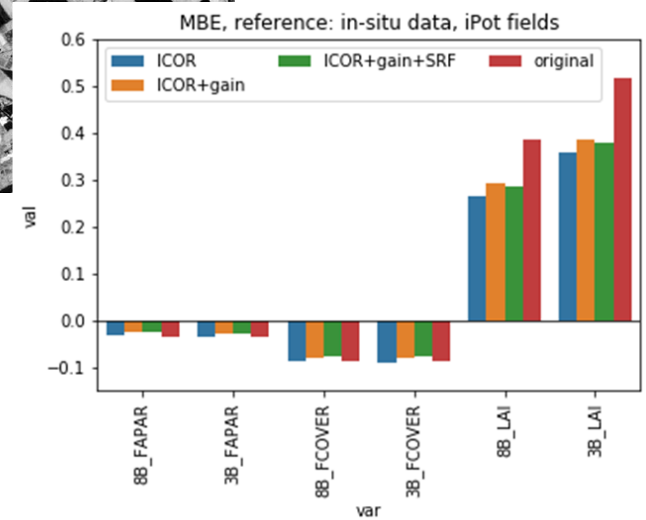
What's the impact of all the harmonisation measures ?

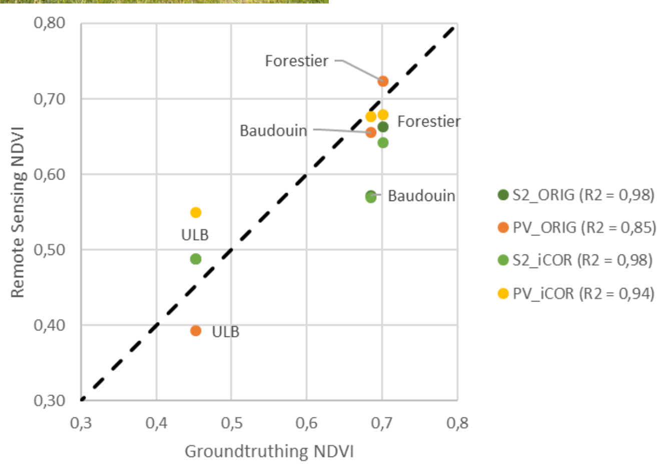


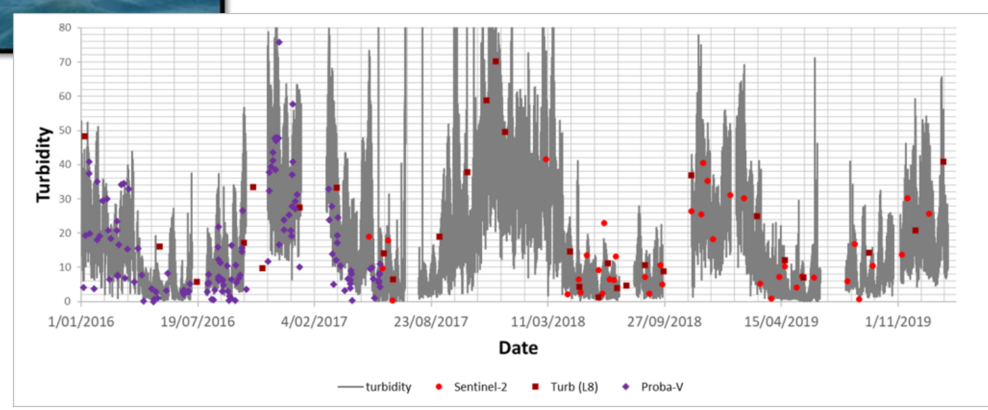
VALIDATION OVER BELAIR SITES

1. Validation with in-situ data





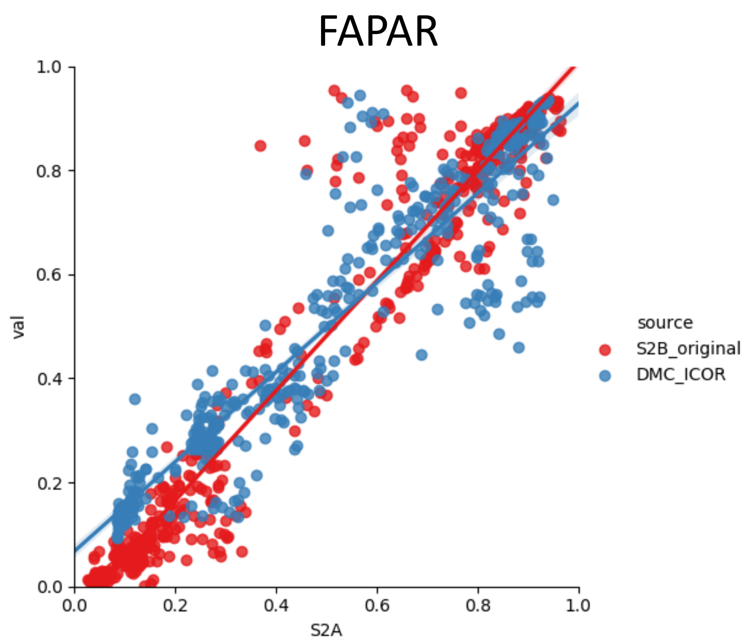


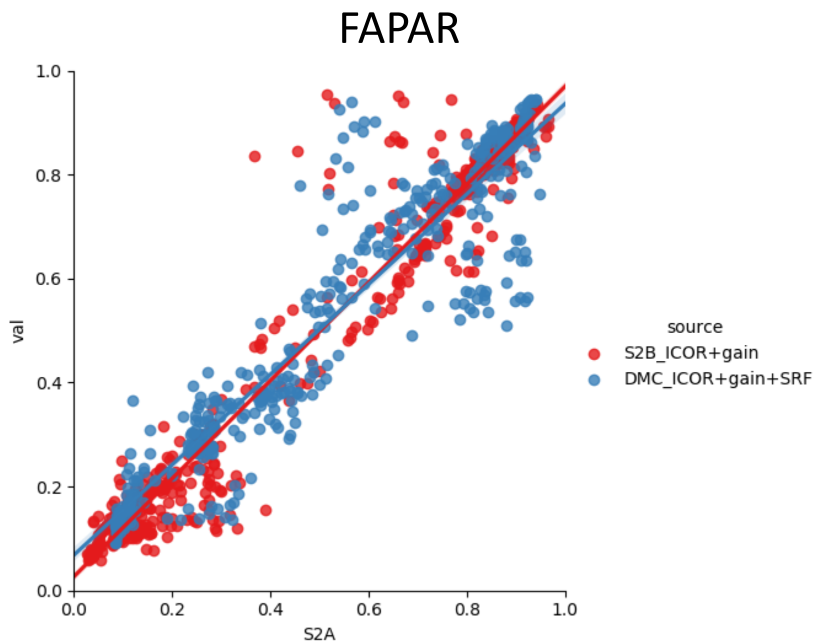


VALIDATION OVER BELAIR SITES

1. **Validation with in-situ data**

2. **Matchups between sensors**



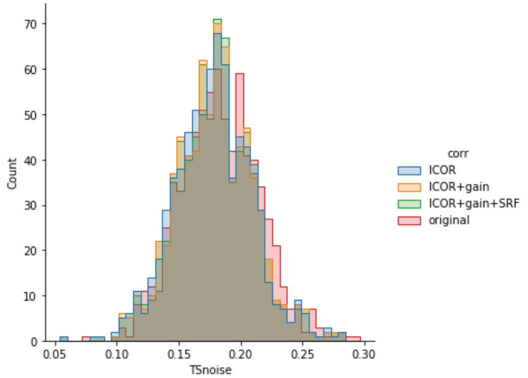


1. **Validation with in-situ data**

2. **Matchups between sensors**

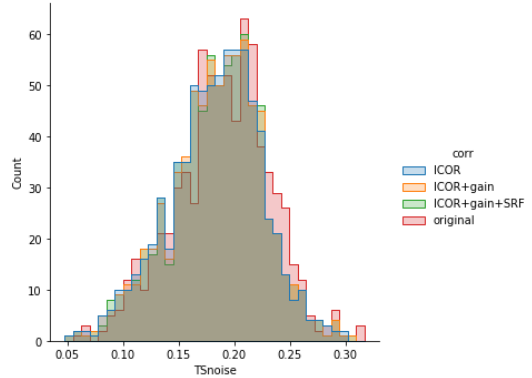
3. **Time series analyses**

FAPAR



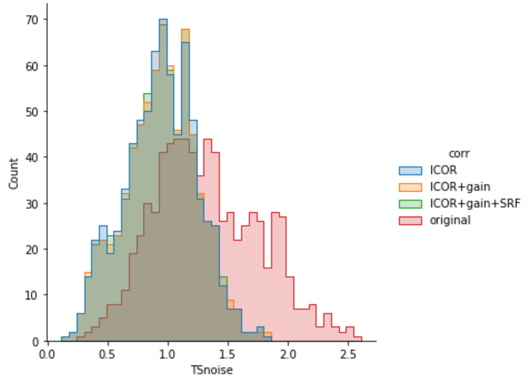
Time series noise

FCOVER



Time series noise

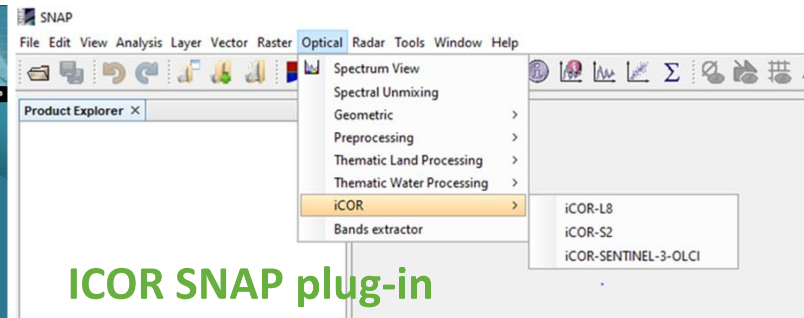
LAI



Time series noise

CONCLUSIONS

- Largest gain of improvement in consistency by applying the same atmospheric correction.
  - ➢ Strength of iCOR: can be applied on various sensors !



- Inter-calibration and SRFs are also important aspects of inter-sensor consistency, but for the considered sensors in Belharmony, only a minor improvement could be seen. Reason for this are that the absolute radiometric calibration of the sensors are close to each other and the spectral bands are defined very similarly.
- BRDF, geometric co-registration not considered in Belharmony

CNR-IIA VUB vito

Thank you!