

VALIDATION OF SENTINEL-2 SURFACE REFLECTANCE PRODUCTS WITH RADCALNET AND HYPERNETS DATA

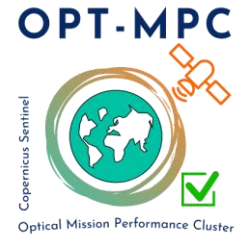
R. De Los Reyes, E. Padilla, D. Marshall Ingram, J. Louis, C. Guerrero, B. Pflug, F.C. Pignatale, F. Poustomis, A. Bialek, P. De Vis, M. Sinclair, A. Zimmermann, R. Morrone, S. Clerc, S. Enache, F. Gascon, V. Boccia



Validation of Sentinel-2 A/B/C L2A Operational products: surface reflectance

- Validation sites used for the SR product validation
- Sentinel-2 Surface Reflectance validation methodology
 - Validation measurands: APU plots.
 - HYPERNETs Gobabeb incorporation
- Sentinel-2 validation results
- Next validation measurands proposed: including uncertainties
- Conclusions

Validation sites for L2A surface reflectance product:



RadCalNet sites monthly downloaded
and evaluated.
HYPERNET land sites under incorporation

Cal/Val Sites

GHNA

Gobabeb HYPERNETS, Namibia



JAES

Jarvselja, Estonia



JSIT

Jolanda di Savoia (FE), Italy



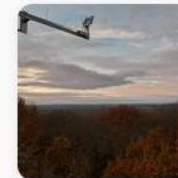
LOBE

Lonze, Belgium



WWUK

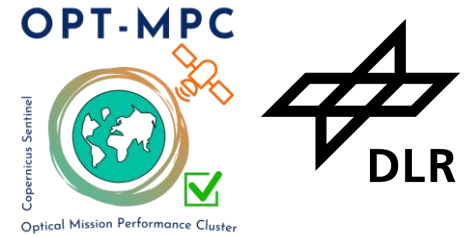
Wytham Woods, UK



HYPERNETS

A new hyperspectral radiometer integrated in automated networks of water and land
bidirectional reflectance measurements for satellite validation

Validation sites characteristics for L2A



Site	Wavelength range [nm]	Sensor viewing [deg]	AOT range [unitless]	WV range [cm]	Biome
La Crau	400.0 - 2400.0	(0, 0)	[0.003 – 0.27]	[0.3 – 5.4]	Semi-arid mediterranean
Gobabeb	400.0 - 2300.0	(0, 0)	[0.004 – 0.4]	[0.2 – 4.0]	Arid desert
Railroad Valley Playa	400.0 - 2300.0	(0, 0)	[0.02 – 0.12]	[0.1 – 2.5]	Arid desert playa
Gobabeb	360.0 – 1687.8	(9, 60)	[0.004 – 0.4]	[0.2 – 4.0]	Arid desert
Jolanda di Savoia			---	---	Agricultural
Lonzee			---	---	Agricultural
Wytham Woods			---	---	Deciduous forest
Jarvselja			---	---	Mixed forest

Next to be incorporated....

Sentinel-2 Surface Reflectance validation

- Sentinel-2 A/B/C overpass over SR validation sites
- Temporal:
 - ± 30 min (± 7.5 deg) of the overpass $\rightarrow$ interpolation in time (and θ_s, ϕ_s)
 - Excluded scenes if no/bad **insitu** data acquisition in $\Delta t > \pm 30$ min.
- **RadCalNet**:
 - Spatial: ROI of the RadCalNet site (Coefficient of Variation)
 - CV versus $U_{ROI, SR}$:
 - 3% for a ROI = 500x500 m (La Crau, Gobabeb)
 - 1.5% for a ROI = 1 x 1 km (Railroad Valley Playa)
- **HYPERNETS**:
 - Viewing Angles (θ_v, ϕ_v):
 - interpolation (polar coordinates) to same BRDF conditions
 - Spatial: $U_{ROI, SR}$:
 - Gobabeb: CV = 3% (ROI = 500 x 500 m)
 - Other: **0%** (ROI of 3x3 pixels)

$$CV[\%] = 100 \times \frac{\sigma}{\mu}$$

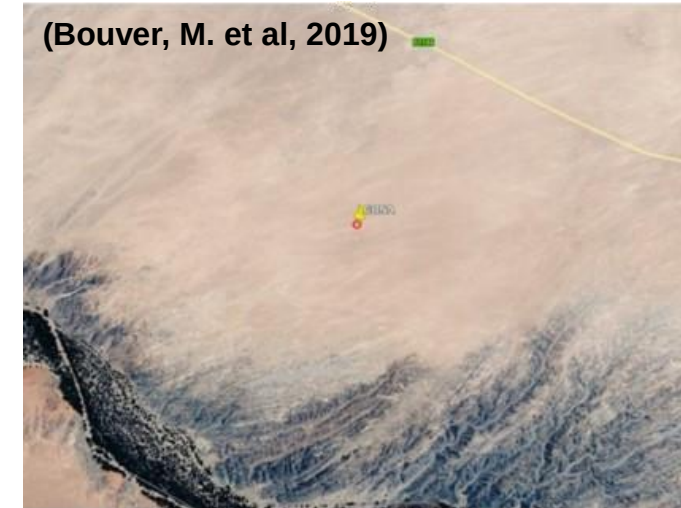


Figure 4: The Gobabeb site and the target for which the RadCalNet top-of-atmosphere reflectance spectra are representative (red circle).

Uncertainty normalized difference
(ISO ISO/IEC 17043:2023(E))

$$E_n = \frac{\rho_{S2} - \rho_{ref}}{\sqrt{U_{S2,SR}^2 + U_{ref}^2}}; \quad |E_n| \leq 1$$

$$U_{ref} = \sqrt{U_{RCN,HYP}^2 + U_{ROI}^2}$$

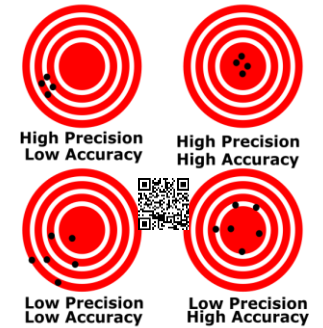
Validation measurands: “APU” plots

$$U_{S2,SR} = 0.05 * \rho_{SR} + 0.005$$

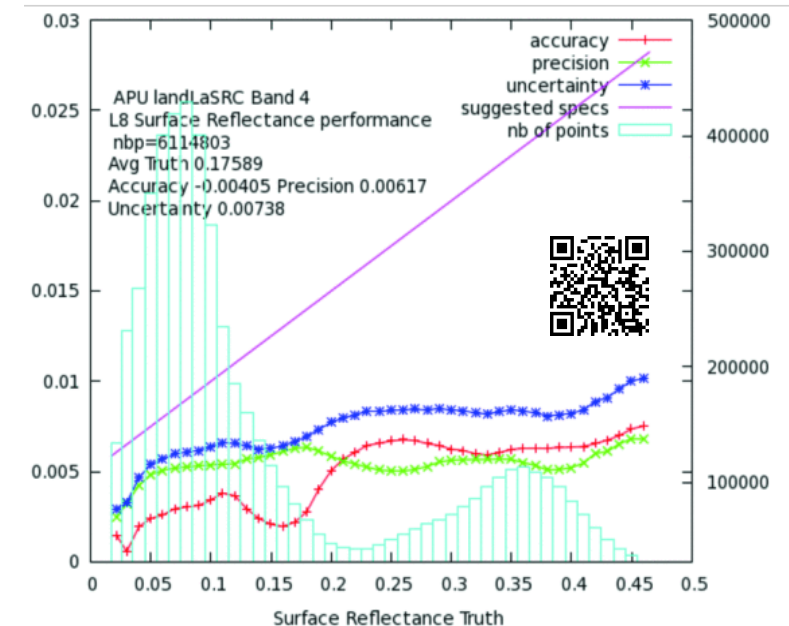
- The requirement measurand is **uncertainty**, often expressed as “accuracy”.
- **U**ncertainty contains **A**ccuracy and **P**recision information.
- **AP** are needed to understand the error source
- But they don’t contain the error of the measurements into consideration. U contains them equally.

$$A = \frac{1}{N} \sum_{i=1}^N \Delta \rho_i \quad P = \sqrt{\frac{1}{N-1} \sum_{i=1}^N (\Delta \rho_i - A)^2} \quad U = \sqrt{\frac{1}{N} \sum_{i=1}^N (\Delta \rho_i)^2}$$

- Next steps.... uncertainties of measurements (U_{S2} , U_{ref})

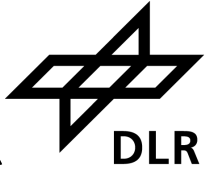


Vermote, et al, 2008



Validation with **uncertainty**: RadCalNet

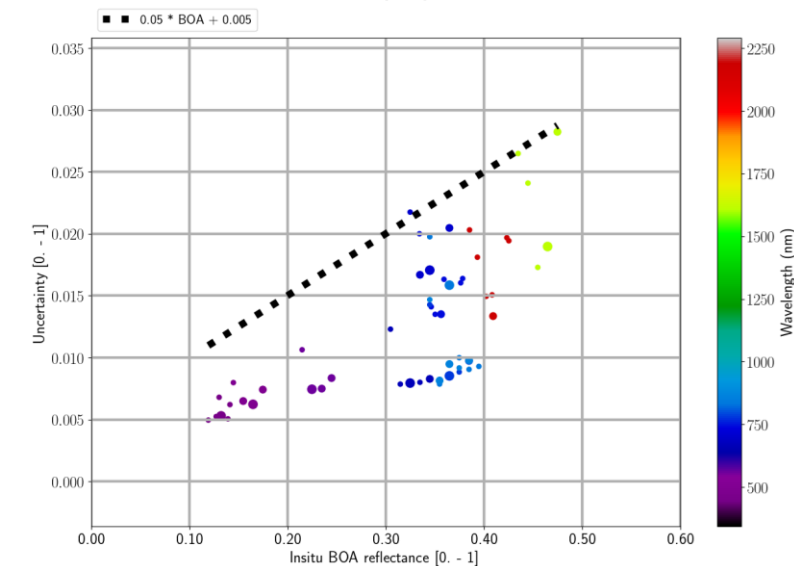
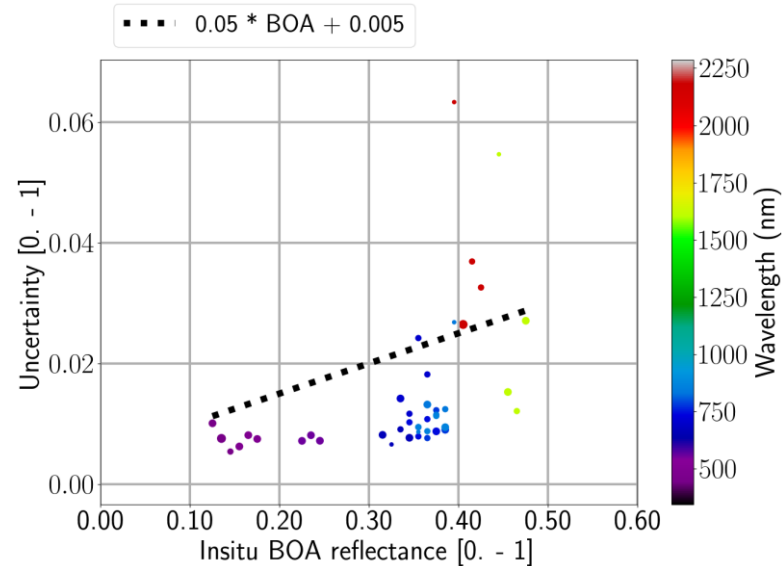
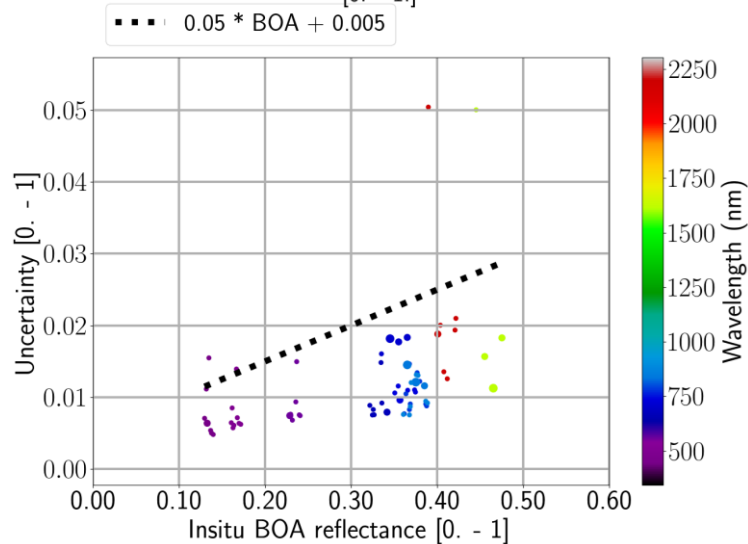
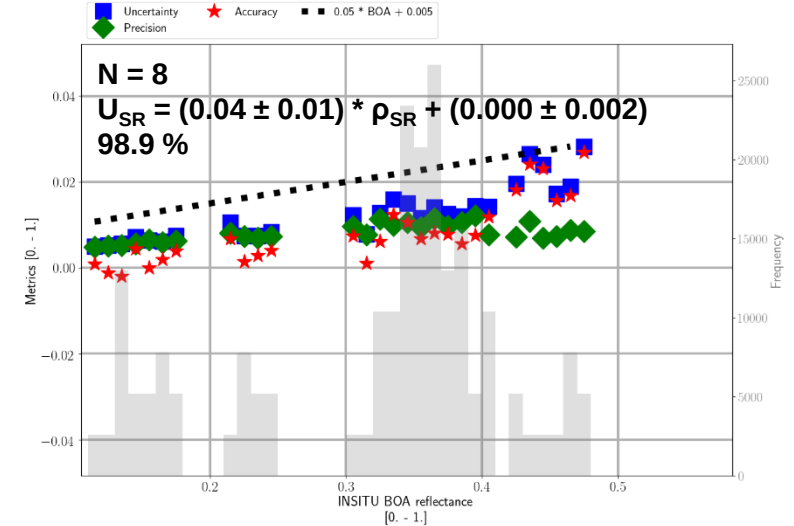
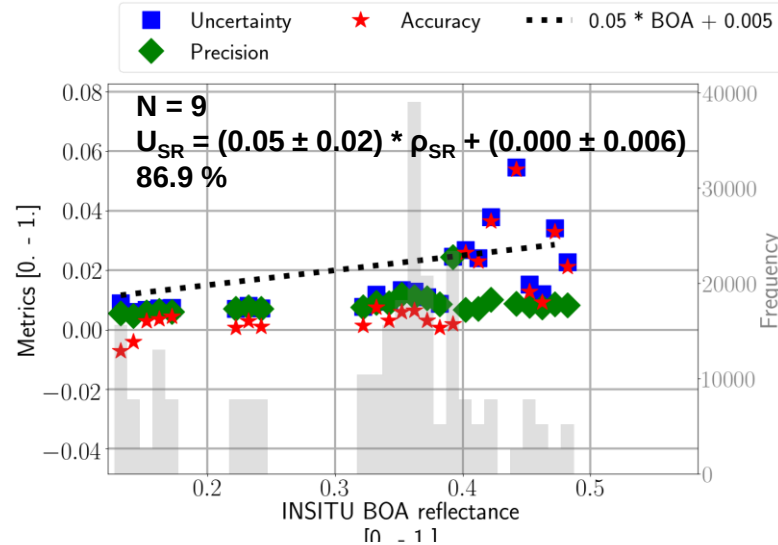
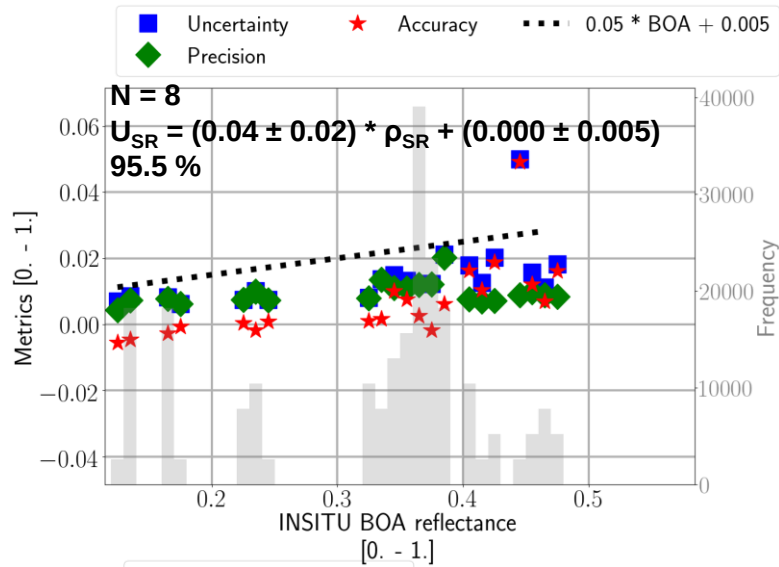
$$U_{S2,SR} = 0.05 * \rho_{SR} + 0.005$$



S2B Gobabeb

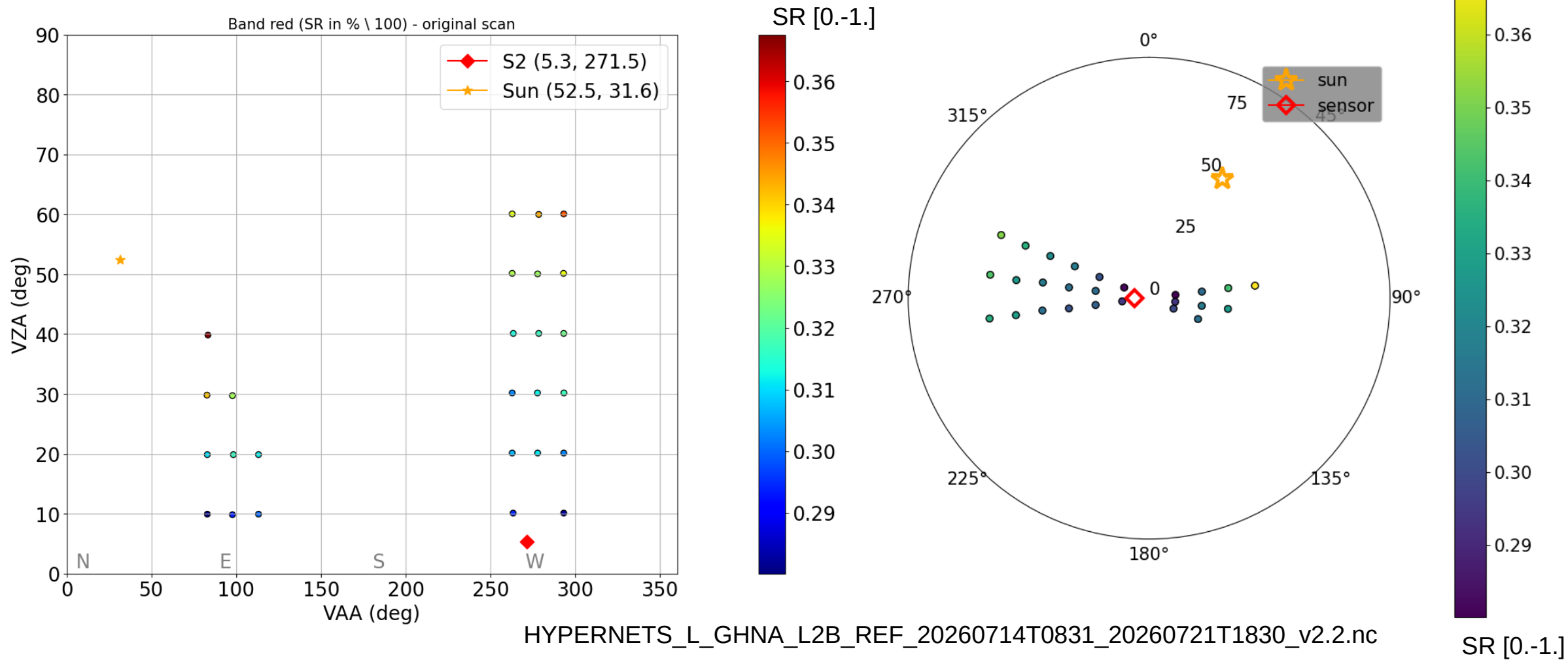
S2C

S2A



Validation with **HYPERNETS**: viewing angle interpolation

Example of HYPERNETS analysis for one day



SR [0.-1.]



Validation with HYPERNETS: example

Multi-sensor overpasses

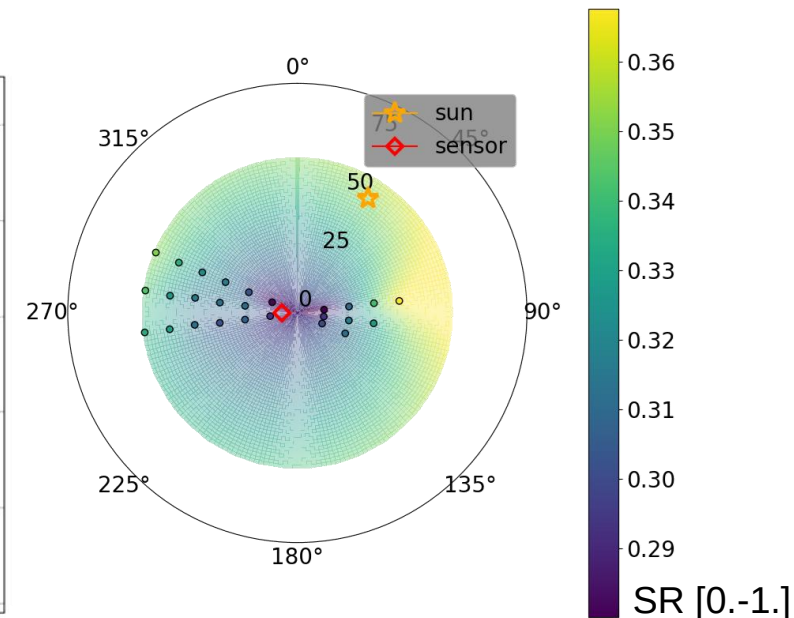
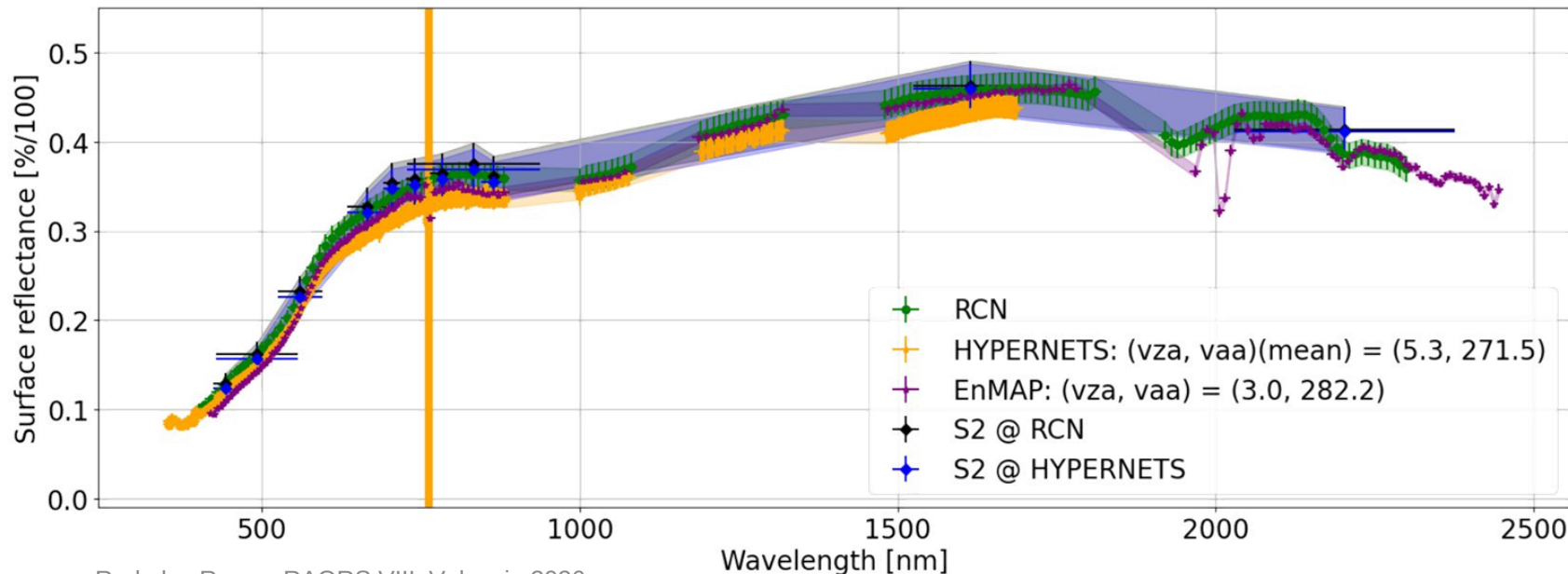
S2 spectra in both sites is consistent with RadCalNet.
Even EnMAP seems to agree.
HYPERNETS discrepancy in NIR-SWIR wavelengths

14.07.2026	UTC	(θ_s, φ_s)	(θ_v, φ_v)
Sentinel-2A	08:47:31	$(52.5^\circ, 31.6^\circ)$	$(5.3^\circ, 271.5^\circ)$
RadCalNet	08:47:31 (*)	$(52.5^\circ, 31.6^\circ)$	$(0.^\circ, 0.^\circ)$
HYPERNET	08:31	$(58.5^\circ, 41.73^\circ)$	$(5.3^\circ, 271.5^\circ)$
EnMAP (**)	09:46:43	$(49.1^\circ, 24.4^\circ)$	$(3.0^\circ, 282.2^\circ)$

(*) RadCalNet is interpolated in time to Sentinel-2 overpass time

(**) EnMAP is forced the AOT to forecast CAMS (AOT ~ 0.06)

HYPERNETS considered at (θ_v, φ_v) S2 bands mean

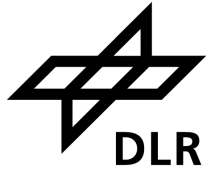


Interpolation in polar coordinates

Sentinel-2 A/B/C SR validation 2026

$$U_{SR,68\%c.l.} = slope * \rho_{SR,ref} + offset$$

$$U_{SR,68\%c.l.} = 0.05 * \rho_{SR,ref} + 0.005$$



	S2A			S2B			S2C		
	%	slope	offset	%	slope	offset	%	slope	offset
La Crau (**)	11.1	0.06 ± 0.02	0.020 ± 0.004	18.2	0.04 ± 0.02	0.016 ± 0.004	10.9	0.04 ± 0.03	0.023 ± 0.007
Gobabeb	95.5	0.04 ± 0.02	0.000 ± 0.005	86.9	0.05 ± 0.02	0.000 ± 0.006	98.9	0.04 ± 0.01	0.000 ± 0.002
Railroad Valley Playa(**)	14.8	0.04 ± 0.02	0.017 ± 0.008	22.7	0.02 ± 0.02	0.032 ± 0.008	22.7	0.01 ± 0.02	0.029 ± 0.006
Gobabeb	58.3	0.07 ± 0.02	0.000 ± 0.005	53.8	0.07 ± 0.01	0.000 ± 0.004	34.0	0.10 ± 0.02	0.005 ± 0.007
Jarvselja (*)		--- ± ---	--- ± ---		--- ± ---	--- ± ---		--- ± ---	--- ± ---
Jolanda di Savoia (*)		--- ± ---	--- ± ---		--- ± ---	--- ± ---		--- ± ---	--- ± ---
Lonzee (*)		--- ± ---	--- ± ---		--- ± ---	--- ± ---		--- ± ---	--- ± ---
Wytham Woods (*)		--- ± ---	--- ± ---		--- ± ---	--- ± ---		--- ± ---	--- ± ---

(*) 3x3 pixels ROI sites

(**) Site probably BRDF affected: investigation on going

Validation considering also the uncertainties of the measurements: Uncertainty Normalized difference

$$E_n = \frac{\rho_{S2} - \rho_{ref}}{\sqrt{U_{S2,SR}^2 + U_{ref}^2}}; |E_n| \leq 1$$

$$U_{ref} = \sqrt{U_{RCN,HYP}^2 + U_{ROI}^2}$$

$$U_{RCN,HYP} = \sqrt{U_{rand}^2 + U_{sys}^2}$$

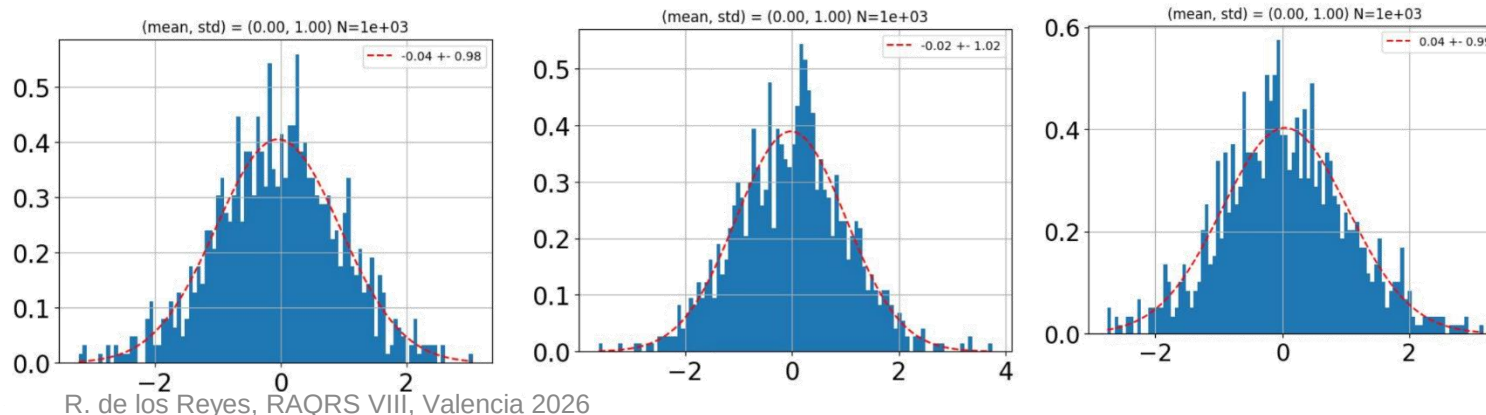
- $U_{S2,SR}$ is unknown but it is required to be

$$U_{S2,SR} \leq 0.05 * \rho_{ref} + 0.005 = U_{S2,REQ}$$

- Considering $U_{S2,REQ}$ as upper limit of $U_{S2,SR}$ ->

$$E_n = \frac{\rho_{S2} - \rho_{ref}}{\sqrt{U_{S2,REQ}^2 + U_{ref}^2}}; |E_n| \leq 1$$

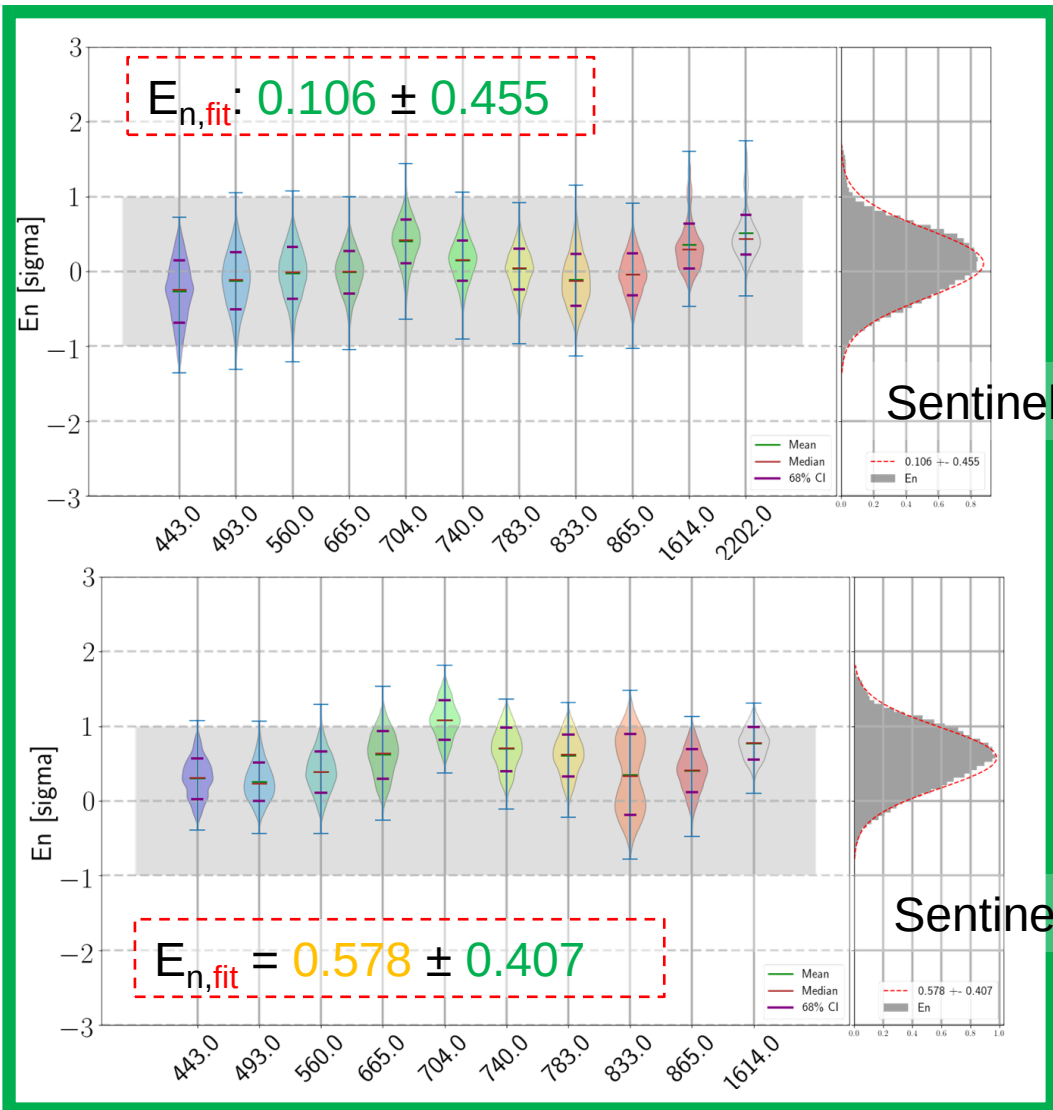
- Idea: when $\rho_{S2} - \rho_{ref}$ is due only to random errors coming from the data



E_n ideally would follow a Gaussian distribution:

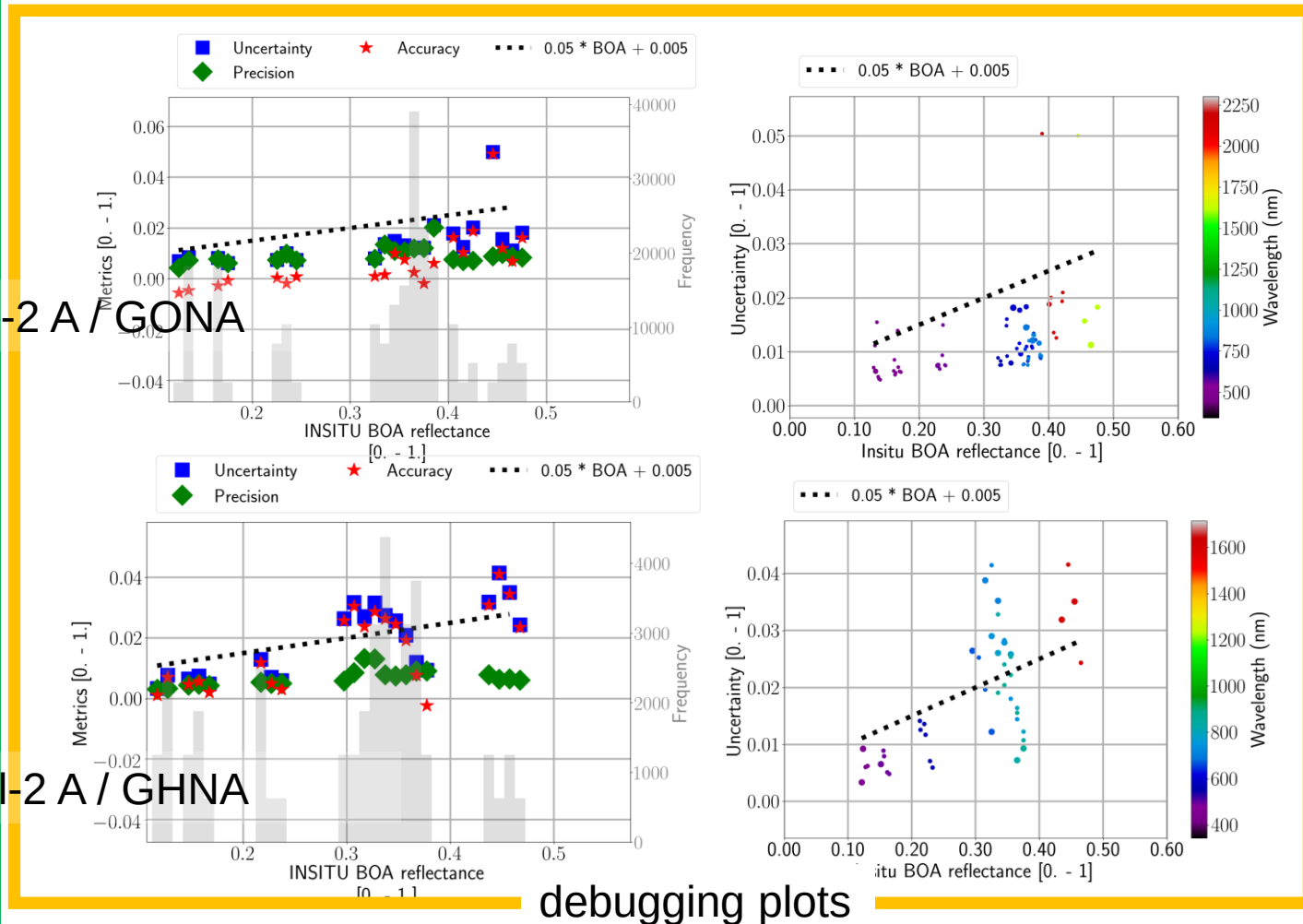
- Mean = 0.0
- Std = 1.0 σ (68% c.l.)
 - > 1.0 -> underestimation of U
 - < 1.0 -> overestimation of U

Next SR validation plots: multi-spectral



$$E_n = \frac{\rho_{S2} - \rho_{ref}}{\sqrt{U_{S2,SR}^2 + U_{ref}^2}}; |E_n| \leq 1$$

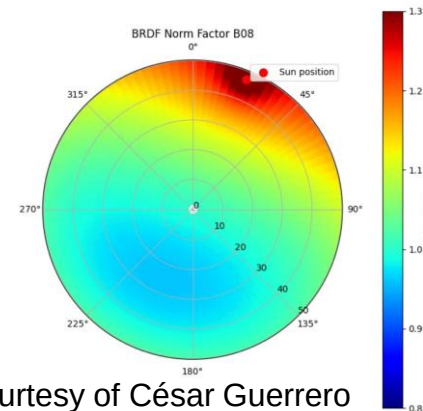
$$U_{S2,SR} = 0.05 * \rho_{SR} + 0.005$$



debugging plots

Conclusions

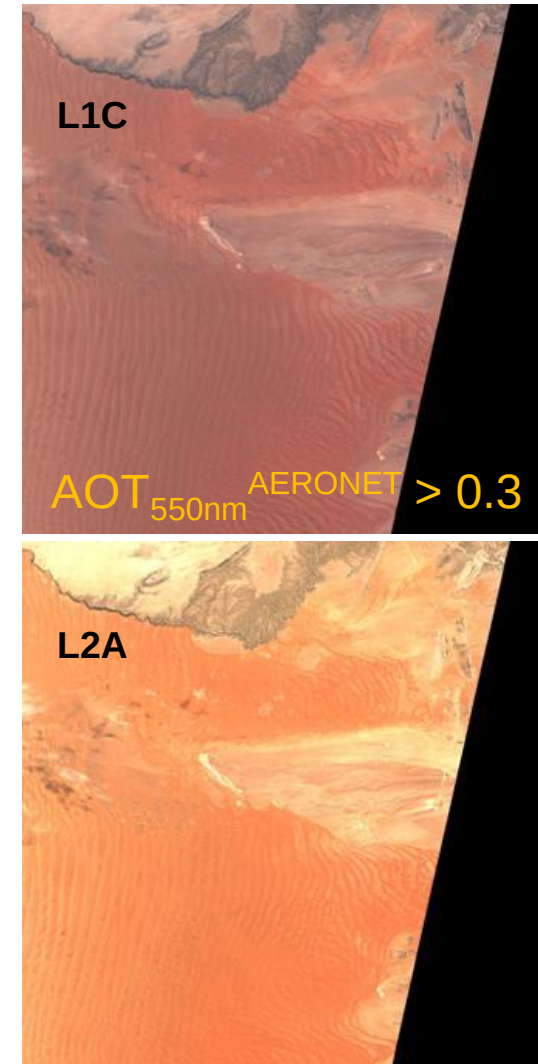
- Good quality of Sentinel-2 L2A SR products ($\ll U_{\text{req}}$ in Gobabeb RadCalNet). Consistent L2A products quality along the years: same fitting results within errors.
- Systematics found for B12 band are not visible in all sites, only for Gobabeb: analysis on the source is on the way.
- Validation over Northern & Southern Hemispheres.
- Thanks to HYPERNETS: increases of biome representativeness.
- Preliminary results with HYPERNETS: $P_{\text{HYPERNETS}} = P_{\text{RadCalNet}}$, $A_{\text{HYPERNETS}} > A_{\text{RadCalNet}}$
- Measurand plots (based on E_n), including the uncertainties of the measurements: $U_{\text{sensor}} \sim U_{\text{req}}$, where $U_{\text{req}} = f(\rho_{\text{ref}}, \lambda, \dots)$
- Next steps:
 - split validation under low/high AOT conditions
 - interpolation (θ_v, ϕ_v) in BRDF kernel models (e.g. HABA) rather in the SR
 - inter-comparison tandem phase. Results will be soon communicated



Courtesy of César Guerrero

❖ **Special L2A-thanks to sites** acquiring SR data under difficult atmospheric conditions ($\text{AOT} \gg 0.1$)

Sentinel-2 C 10.09.2026



Topic: **Validation of Sentinel-2 surface reflectance products with RadCalNet and HYPERNETS**

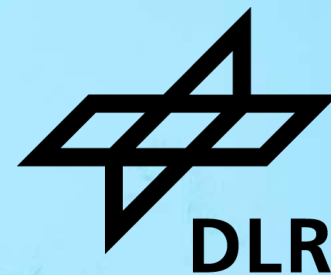
Date: 2026-09-24

Author: Raquel de los Reyes

Institute: Remote Sensing Technology Institute

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Gobabeb

