Current and future radiometric calibration and validation of hyperspectral imaging systems at CNES

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Introduction

- Radiometric calibration links digital values to radiance, providing physical meaning to the image.
- Calibration enhances data quality in optical remote sensing and enables combining measurements from multiple instruments.
- The large number of bands and the wide spectral range of hyperspectral missions push traditional radiometric calibration methods to their limits.
- This presentation showcases current and future means of radiometric calibration for hyperspectral imaging systems at CNES and presents key calibration results obtained from these systems.

CNES legacy on radiometric cal/val on multispectral sensors

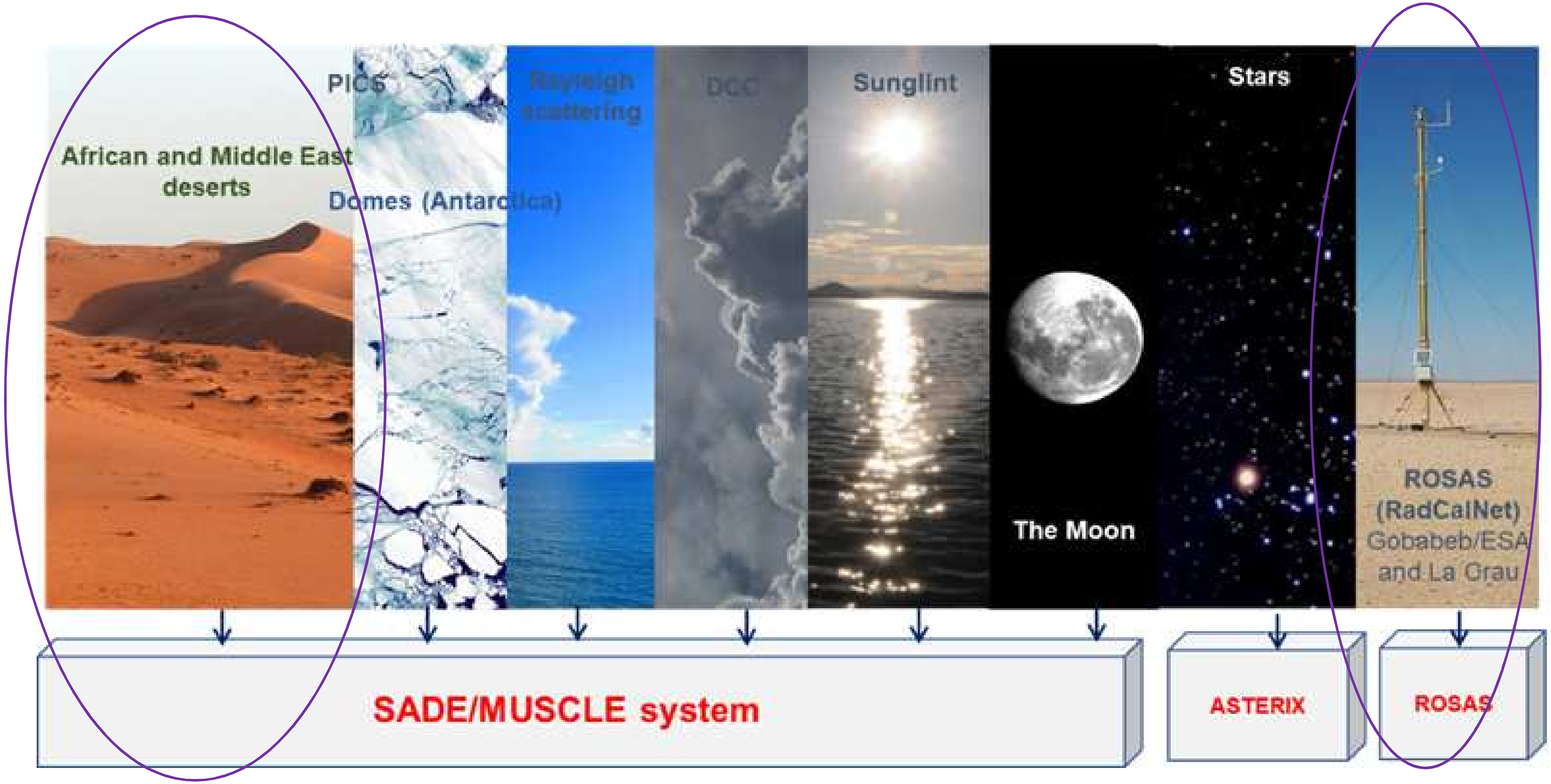
Over the last two decades, CNES has calibrated and cross-calibrated a wide range of multispectral imaging systems …

CNES legacy on radiometric cal/val on multispectral sensors

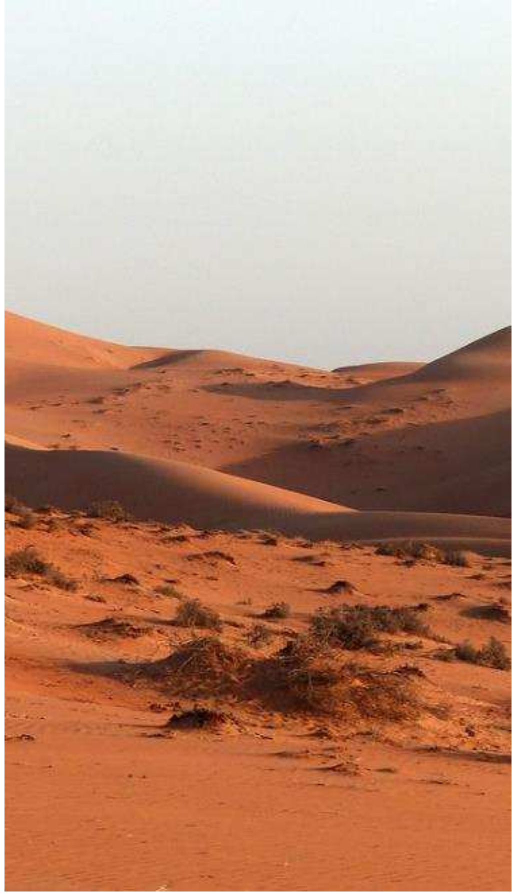
… using several vicarious calibration methods

- Calibration methods use several sensor acquisitions on natural targets
- Calibration methods are based on physical principles
- Principle of all methods: compare a sensor measurement to a simulated one (from a model or a reference sensor)

Ongoing adaption of vicarious methods to hyperspectral imagers



Cross-calibration method based on PICS (warm deserts)



Purpose:

- Inter-calibration between different sensors operating simultaneously or at different time
- Validation of sensor's temporal stability throughout its entire lifetime

Hypothesis:

- 20 arid areas (African and Middle East deserts) do not change over time
- Two images acquired by different instruments, with similar solar and acquisition geometries, over such area can be compared after atmospheric corrections

Data used:

- Mean reflectance over standard (100 x 100 km²) or small (~ 20 x 20 km²) desert sites
- Exogenous data for the atmosphere

Calibration results:

- Cross-calibration coefficient $\Delta A_k = \frac{\rho_k^{Sensor\_2}}{\rho_k^{ref.sensor}}$

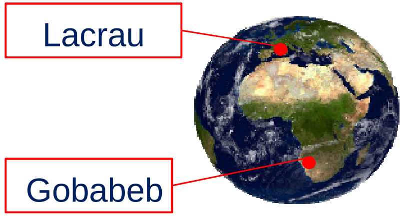
Calibration with ROSAS instrumented sites

Hypothesis:

- The *in situ* measurements are available and representative of the imaged area.

Method and data used:

- Mean reflectance over the LaCrau and Gobabeb sites measured by the spaceborne sensor
- In-situ measurements in 12 bands everyday: BRDF and atmosphere
  -> These measurements are used to fit a hyperspectral spectrum which was measured during a field campaign
  -> gives us surface reflectance measurements in the same angular conditions as the optical sensor to calibrate
- Automatic field instrumentation
- Nadir data accessible to the public via RadCalNet



Calibration results:

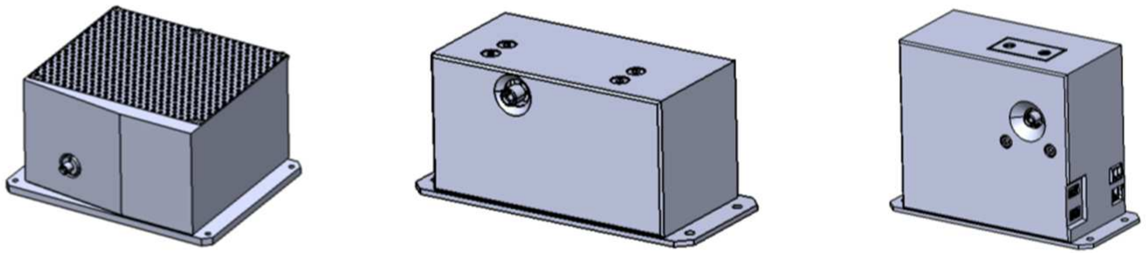
- Absolute calibration coefficient $A_k = \frac{\rho_k^{measured}}{\rho_k^{in\,situ}}$

Band	1	2	3	4	5	6	7	8	9	10	11	12	13
λ(nm)	414Si	440Si	500Si	550Si	675Si	702Si	740Si	782Si	870Si	937Si	1020Si	1020 InGaAs	1640 InGaAs

Calibration with ROSAS instrumented sites: future evolutions

- Development of an hyperspectral instrument to improve in-situ measurements and to anticipate calibration needs of future hyperspectral missions
- Contract with CIMEL who assembles 3 OEM spectrometers made by HORIBA
- Prototype deployment on La Crau site planned in 2024

Item	HJY Specifications VNIR	HJY Specifications SWIR 1	HJY Specifications SWIR 2
Spectral range	350 – 1050 nm	1000 – 1700 nm	1600 – 2500 nm
Spectral resolution	< 2 nm	< 5 nm	< 10 nm
Sensor type	Si detector	InGaAs detector	InGaAs detector
Size	150 x 121,5 x 78,5 mm	115 x 52,5 x 52,3 mm	115 x 50 x 87 mm



Application to PRISMA calibration

PRISMA payload main characteristics

Orbit parameters	
Altitude	620 km (nominal)
Period	96 min
Repeat cycle	29 days (430 orbits)
Three mirrors anastigmatic telescope (TMA)	
Effective focal length	620 mm
Entrance Pupil diameter	210 mm
Swath / FOV	30 km / 2.77°
IFOV	48urad
F#	2.95
Hyperspectral sensor	
Spectral range	VNIR 400-1010 nm SWIR 920-2505 nm
Ground Sampling Distance	30 m
Pixels (spatial x spectral)	1000 x 256 pixels
Pixel size	30 µm x 30 µm
Spectral sampling interval	<11 nm
Spectral width	<12 nm
SNR VNIR	>200:1 on 400-1000 nm >500:1 @ 650 nm
SNR SWIR	>200:1 on 1000-1750 nm >400:1 @ 1550 nm >100:1 on 1950-2350 nm >200:1 @ 2100 nm
Panchromatic sensor	
Ground Sampling Distance	5 m
Pixels	Detector 12000 Used 6000
Pixel size	6.5 µm x 6.5 µm
SNR PAN	240
Other parameters	
Abs. Radiometric accuracy	5%
Radiometric quantization	12 bit
Cooling system	Passive radiator
Lifetime	5 years

Application to PRISMA calibration

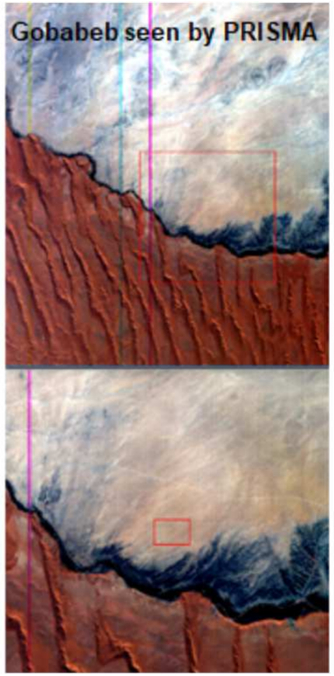
- CNES support ASI for PRISMA radiometric cal/val with vicarious methods

- Following the 2019 vicarious campaign, PRISMA official absolute gains have integrated the feedbacks from CNES
  -> New PRISMA absolute gains aligned with CNES calibration coefficient

- New campaigns were performed in 2022 and 2023

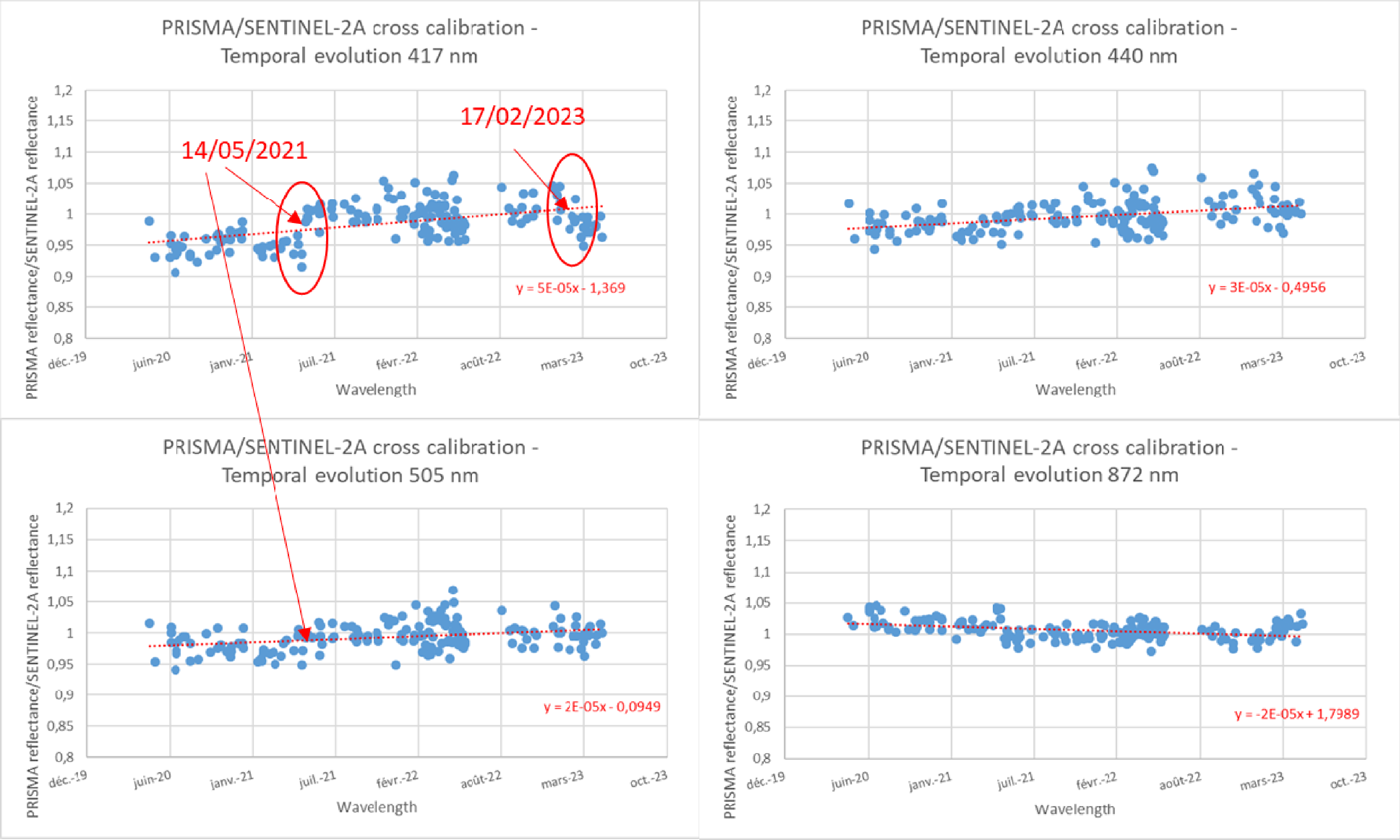
- The 2022 campaign highlighted a sensitivity variation in May 2021

- Following results from the 2023 campaign
  Used PRISMA L1 data:
    189 products on 20 PICS (March 2020 – April 2023)
    15 products on Gobabeb site (May 2022 – February 2023)



Application to PRISMA calibration: temporal evolution over PICS

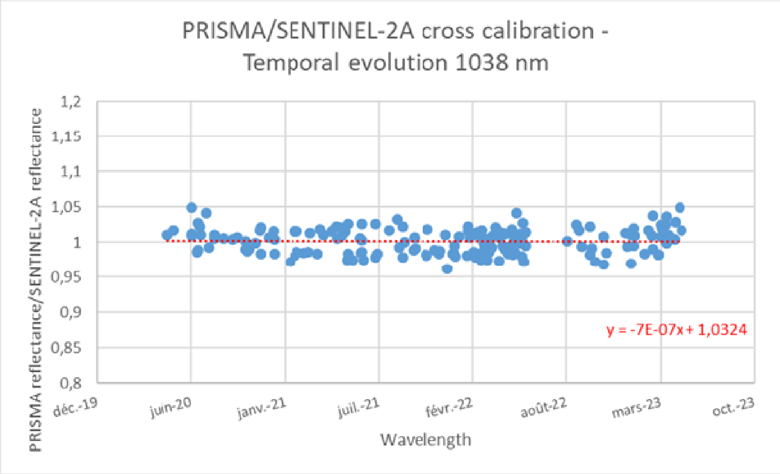
VNIR bands

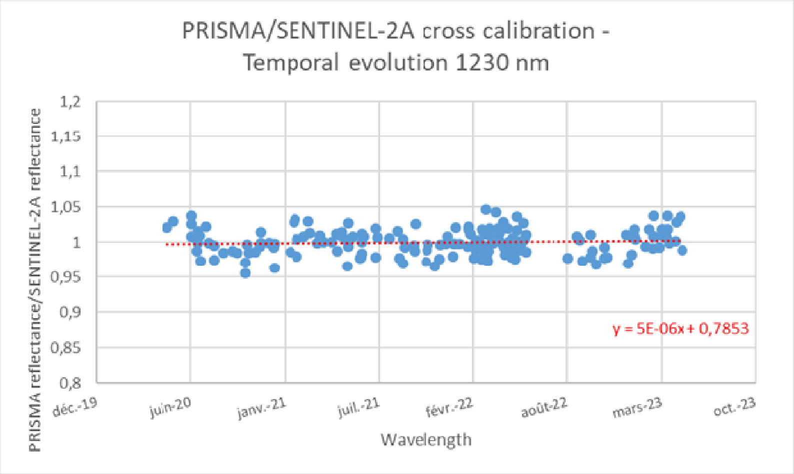


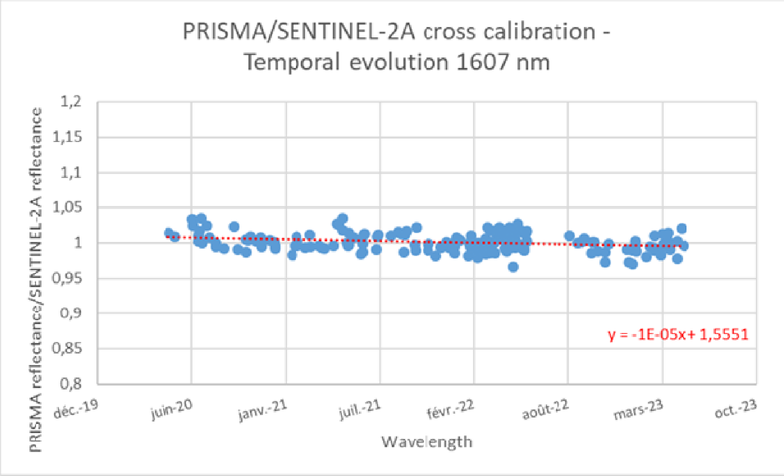
- Short wavelengths:
  3 periods with a relative stability: on board event in May 2021 and February 2023?
- Small sensitivity variation for VNIR bands
  < 1% / year

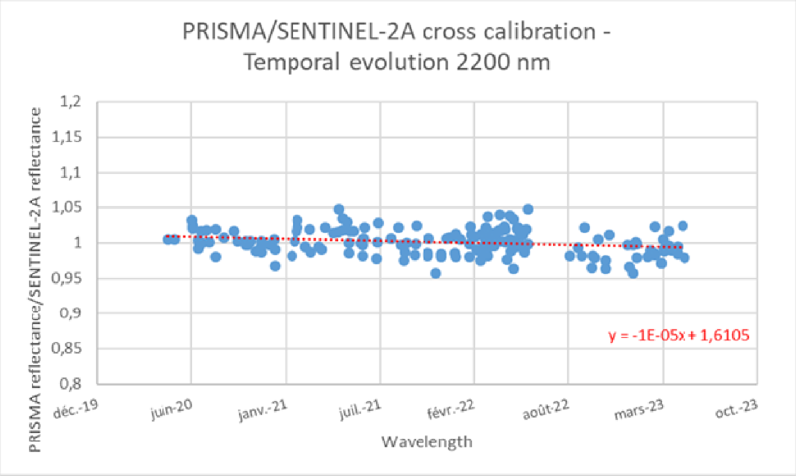
Application to PRISMA calibration: temporal evolution over PICS

SWIR bands





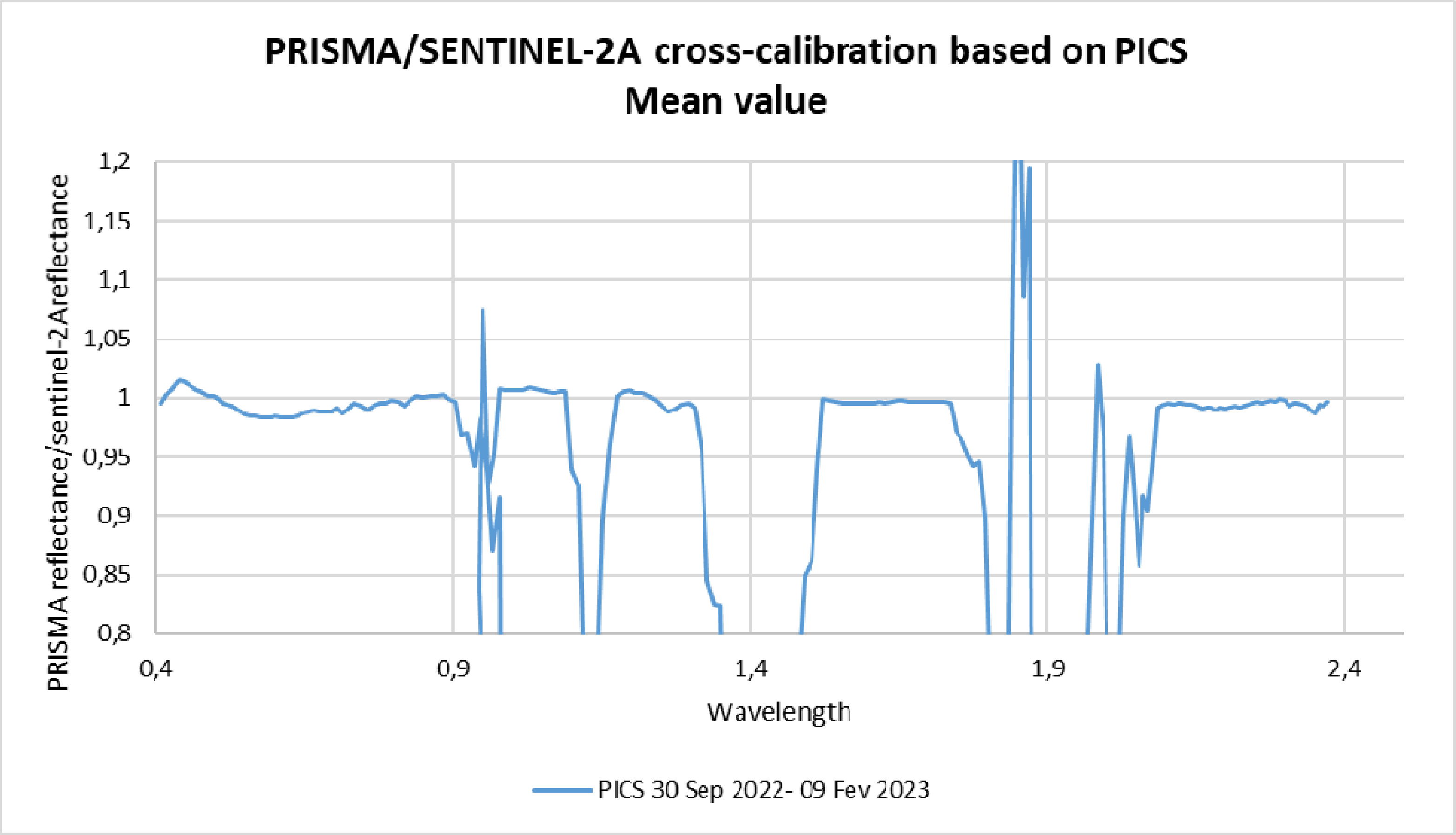




- Very small sensitivity variation for SWIR bands < 0,4% / year

Application to PRISMA calibration: Cross-calibration over PICS with S2A

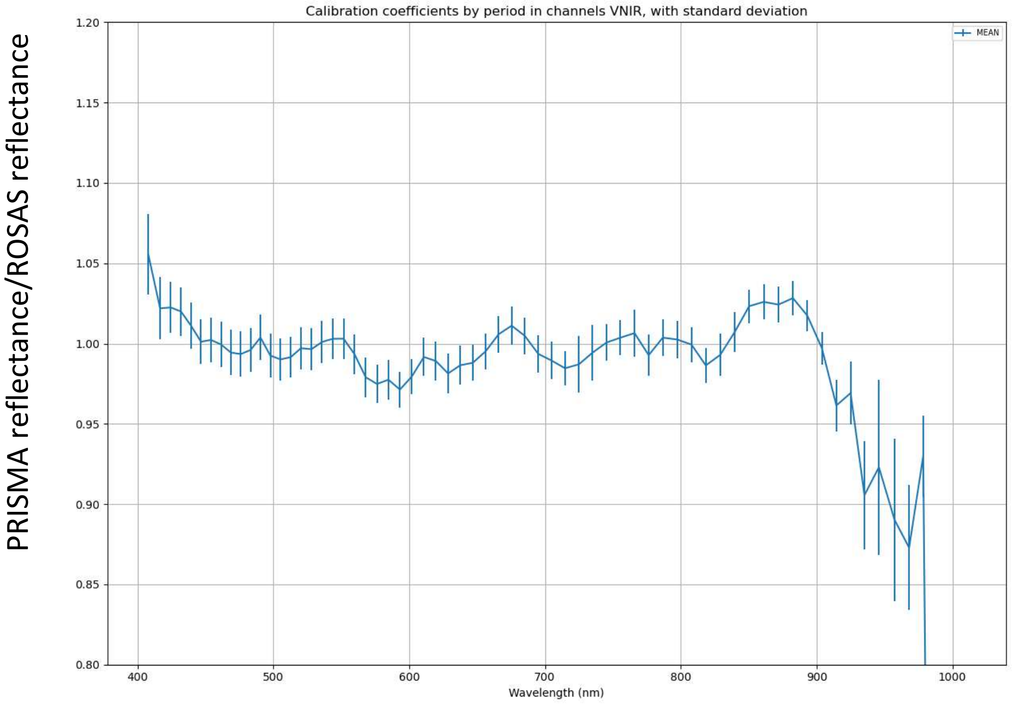
25 products over 8 PICS between Sept 22 and Jan 23

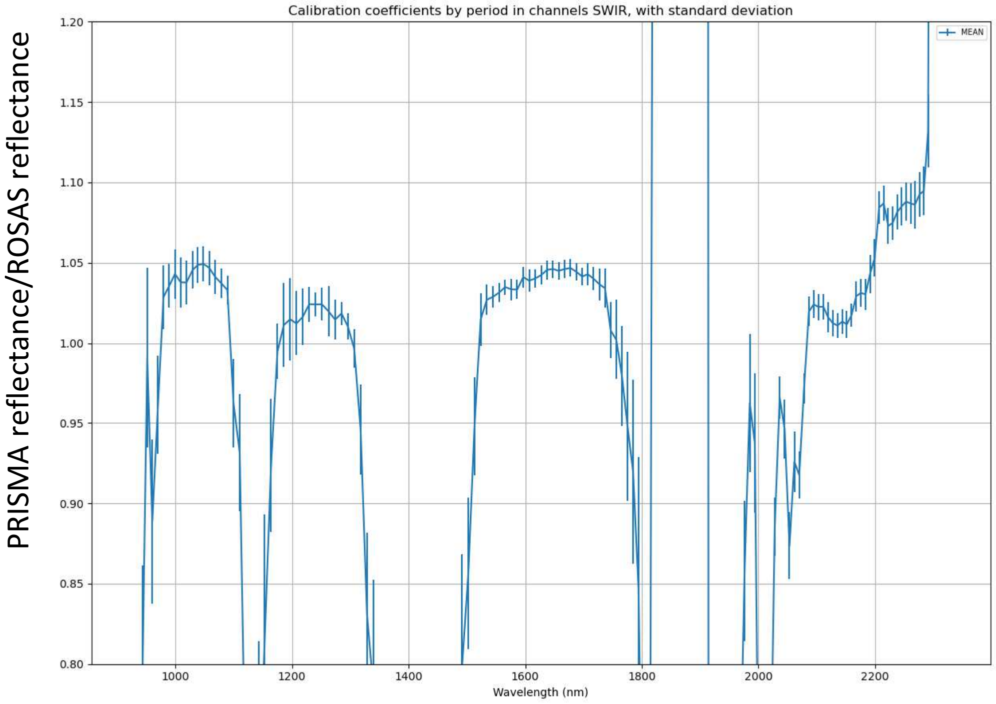


- Small sensitivity variation for VNIR ~2%
- Good stability for SWIR bands

Application to PRISMA calibration: in-situ Gobabeb instrumented site

15 products on Gobabeb site (May 2022 – February 2023)





VNIR:

- First measurement (~ 400 nm) not reliable
  (no photometer band)
- Validation of the official calibration within 2-3 %

SWIR:

- Small bias (<5%) around 1.6µm
  which is the only SWIR channel of ROSAS

PRISMA calibration resume

- Good stability of PRISMA instrument over 3 years:
    - Weak temporal variation < 1% / year
    - « Step » for short wavelengths in May 2021 and to be confirmed in February 2023 (to be decorrelated from the seasonal cycle)

- Official PRISMA calibration is based on CNES cross-calibration with Sentinel-2A over PICS
- Validation with ROSAS in-situ measurements at Gobabeb site:
    - Good consistency between ROSAS and PICS for VNIR bands (2-3%)
    - Higher variation for SWIR bands (4% for 1.6µm) but the in-situ photometer has one band only in the SWIR spectrum

Conclusion

- Ongoing adaption of multispectral vicarious methods for hyperspectral imagers
- Development of an hyperspectral instrument to improve in-situ measurements
- Collaboration with ASI on PRISMA radiometric cal/val activities
- Similar activities ongoing with DLR on Desis & EnMAP sensors