CNES CALIBRATION ACTIVITIES

Aimé Meygret, Sophie Coustance, Camille Desjardins, Arthur Dick,
Thierry Erudel*, Morgan Farges**, Bruno Lafrance*, Lucas Landier, Laura Le Barbier,
Xavier Lenot*, Sébastien Marcq, Robin Marron, Julien Mendes**, Cécile Peschoud*,
Charlotte Revel, Damien Rodat, Stéphanie Bourdeau, Nicolas Guilleminot,
Leandro Chiarantini*****, Laurent Coeudevey***, Massimo Cosi***** ,
Noela Despre***, Ettore Lopinto****, Francesco Sarti*****,

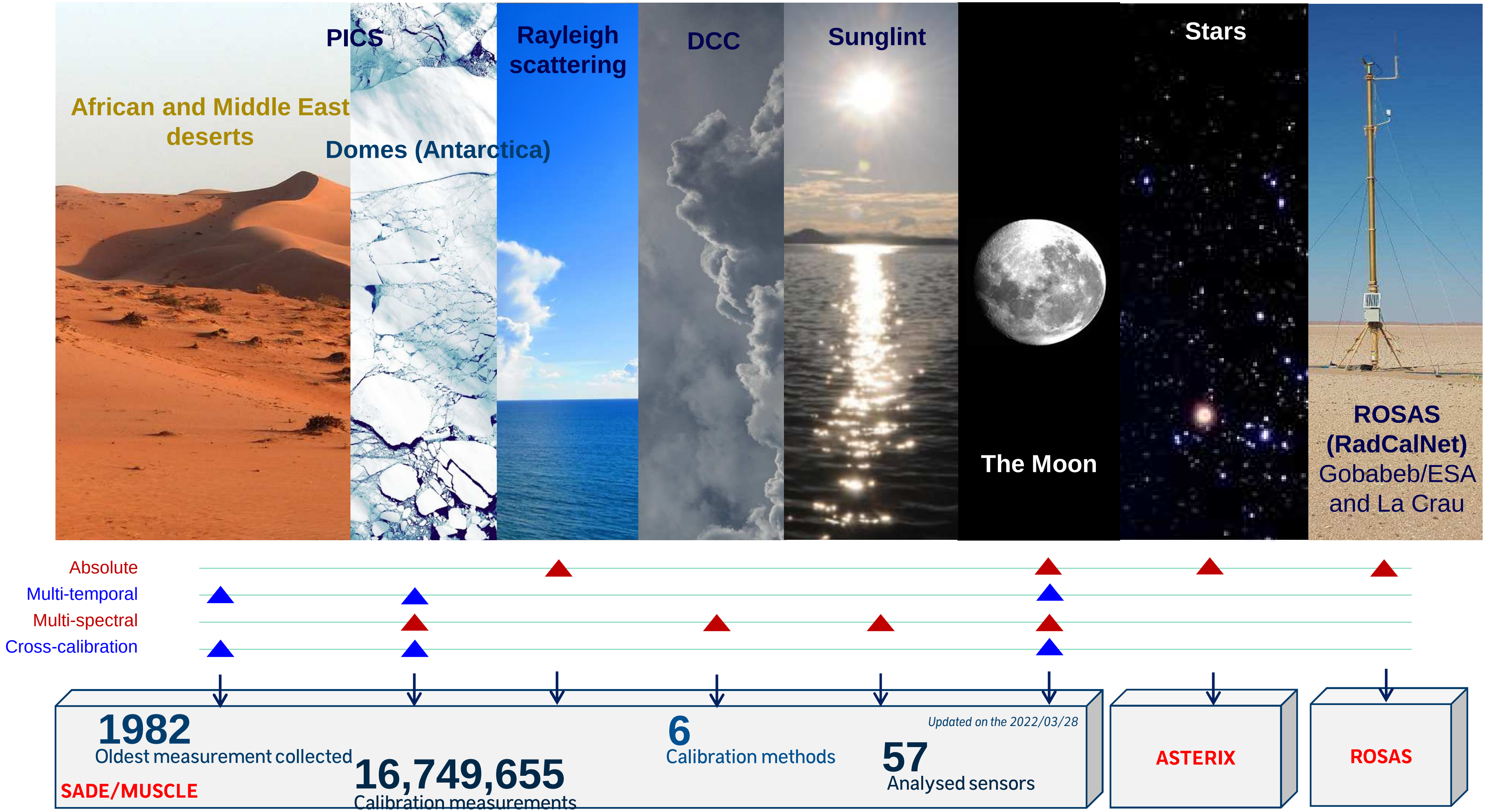
* CS GROUP ** magellium *** AIRBUS cnes **** ASI Agenzia Spaziale Italiana ***** LEONARDO ELECTRONICS

CEOS WGCV IVOS 34, Reston, VA, USA 30/08/2022

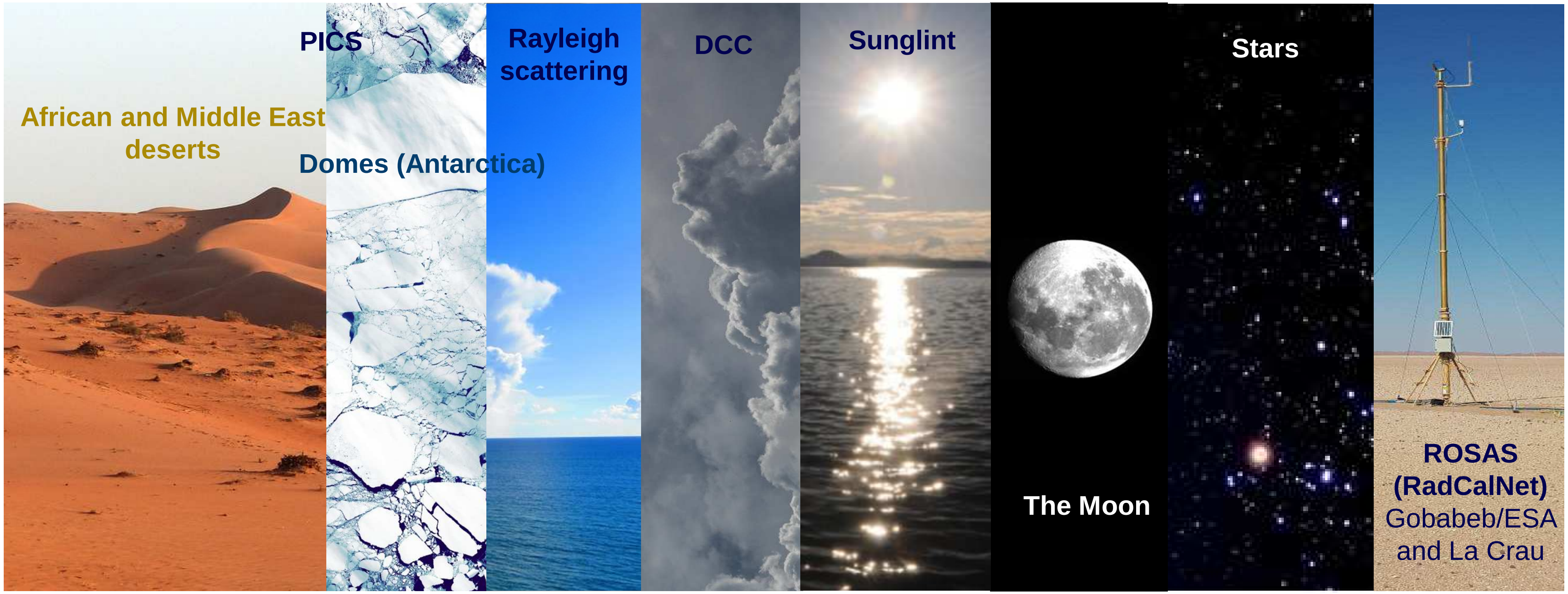
SUMMARY

- CNES vicarious calibration methods
- PNEO 4&5 calibration
- PRISMA calibration
- Sentinel-2 calibration
- Sentinel-3 calibration
- Spot Word Heritage atmospheric correction

CNES VICARIOUS CALIBRATION METHODS



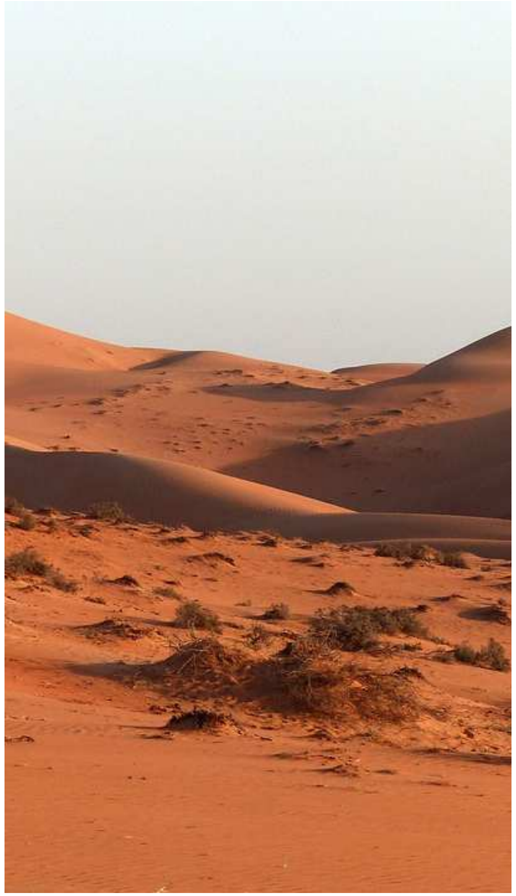
CNES VICARIOUS CALIBRATION METHODS



- Our vicarious calibration methods (except ROSAS and stars) are integrated into a **unified tool** called MUSCLE linked to a **large database** named SADE allowing to perform massive cross-comparisons

- MUSCLE-NEO under development with external access
  - V1 version (same tools as MUSCLE) planned end of 2022
  - V2 version (updated methods) planned end of 2023

CALIBRATION METHOD BASED ON PICS (WARM DESERTS)



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:

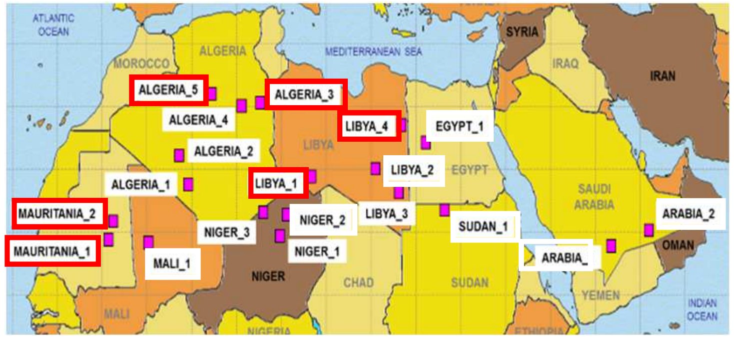
- **Mean reflectance over standard (100 x 100 km²) or small (~ 20 x 20 km²) desert sites**

- **Exogenous data for the atmosphere**

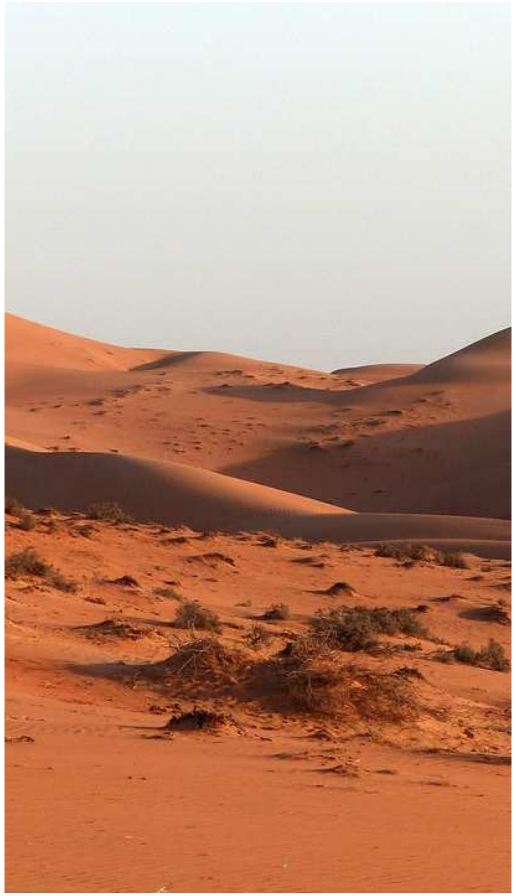
CEOS sites

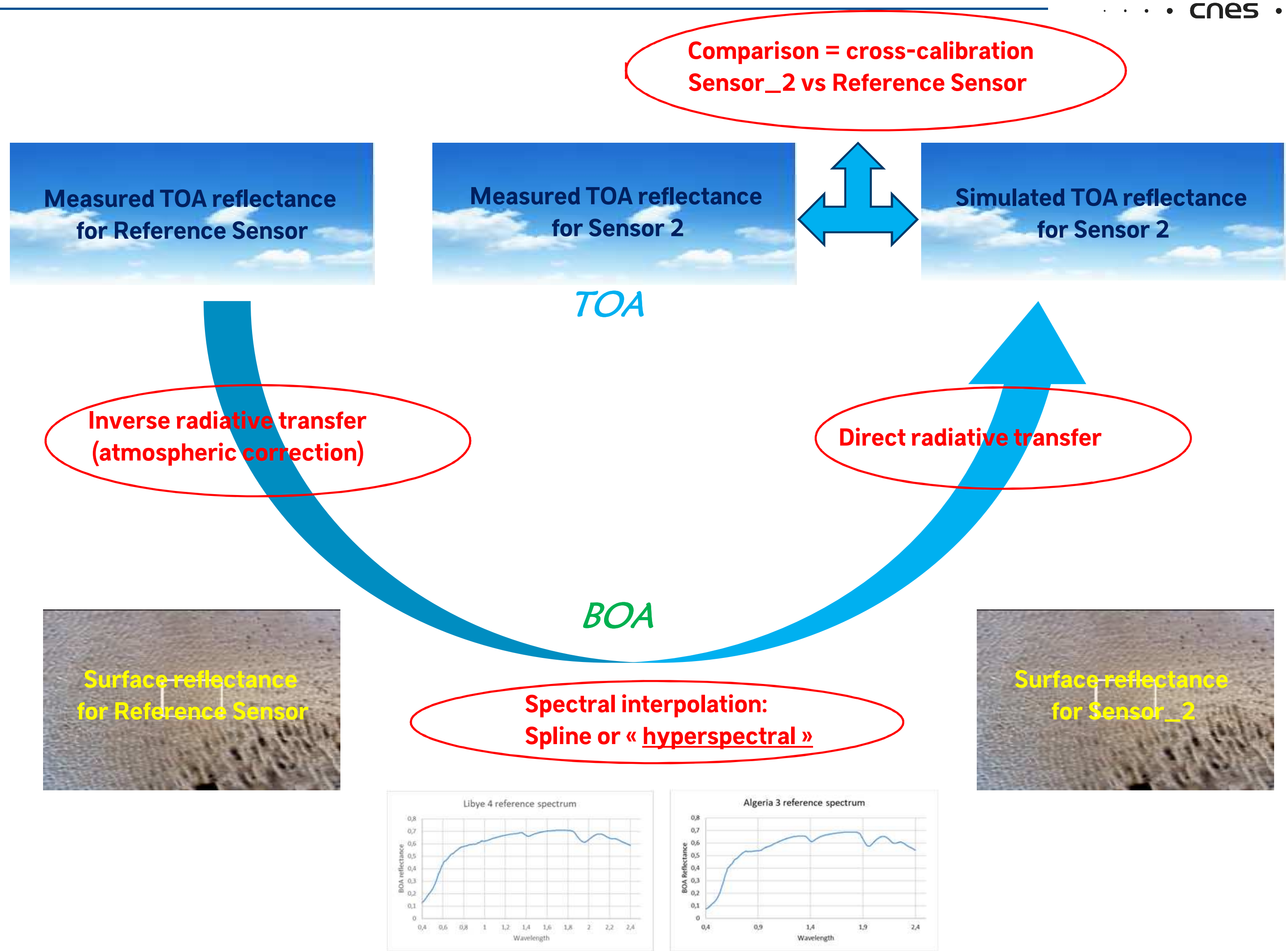
Calibration results:

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



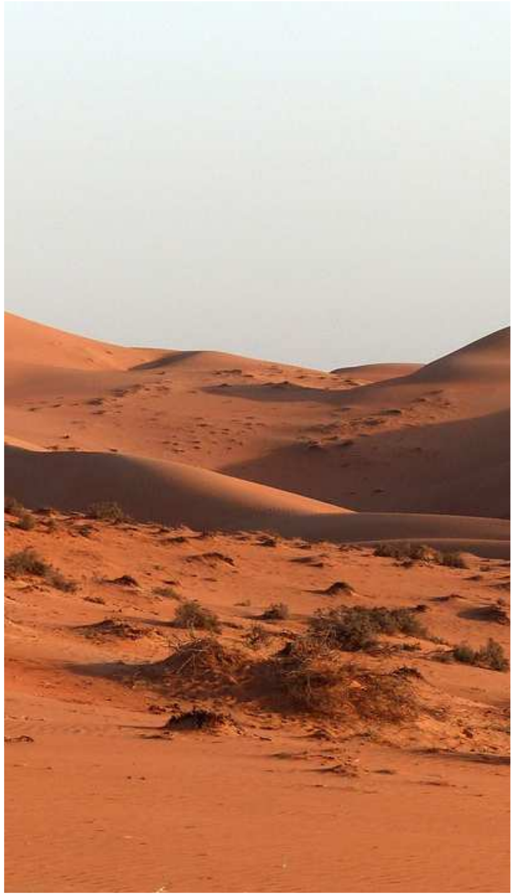
CALIBRATION METHOD BASED ON PICS (WARM DESERTS)





What's new?

⇒ Reference spectra construction to improve the BOA reflectances spectral interpolation



Preselection of hyperspectral libraries (ONERA lab measurements, GOME-2, ECOSTRESS, PICSAND) by comparison to SENTINEL-2 MSI and SENTINEL-3 OLCI:

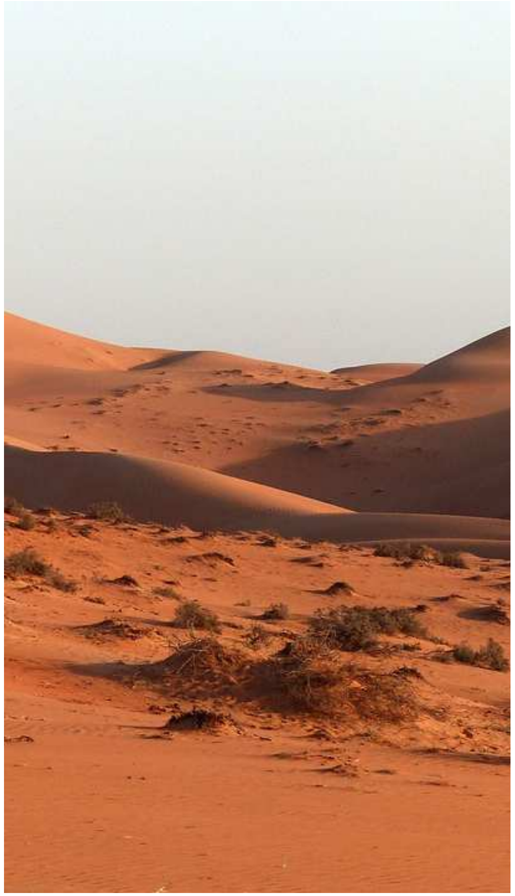
- Use of all the available measurements (SADE Data Base).
- Median spectra for MSI and OLCI computed for each site.
- Cross-band correction based on DCC calibration
- MSI/OLCI bias correction based on PICS calibration
- BOA reflectances computed using SMAC modeling.
- BOA reflectances BRDF correction based on Snyder model (nadir normalization)

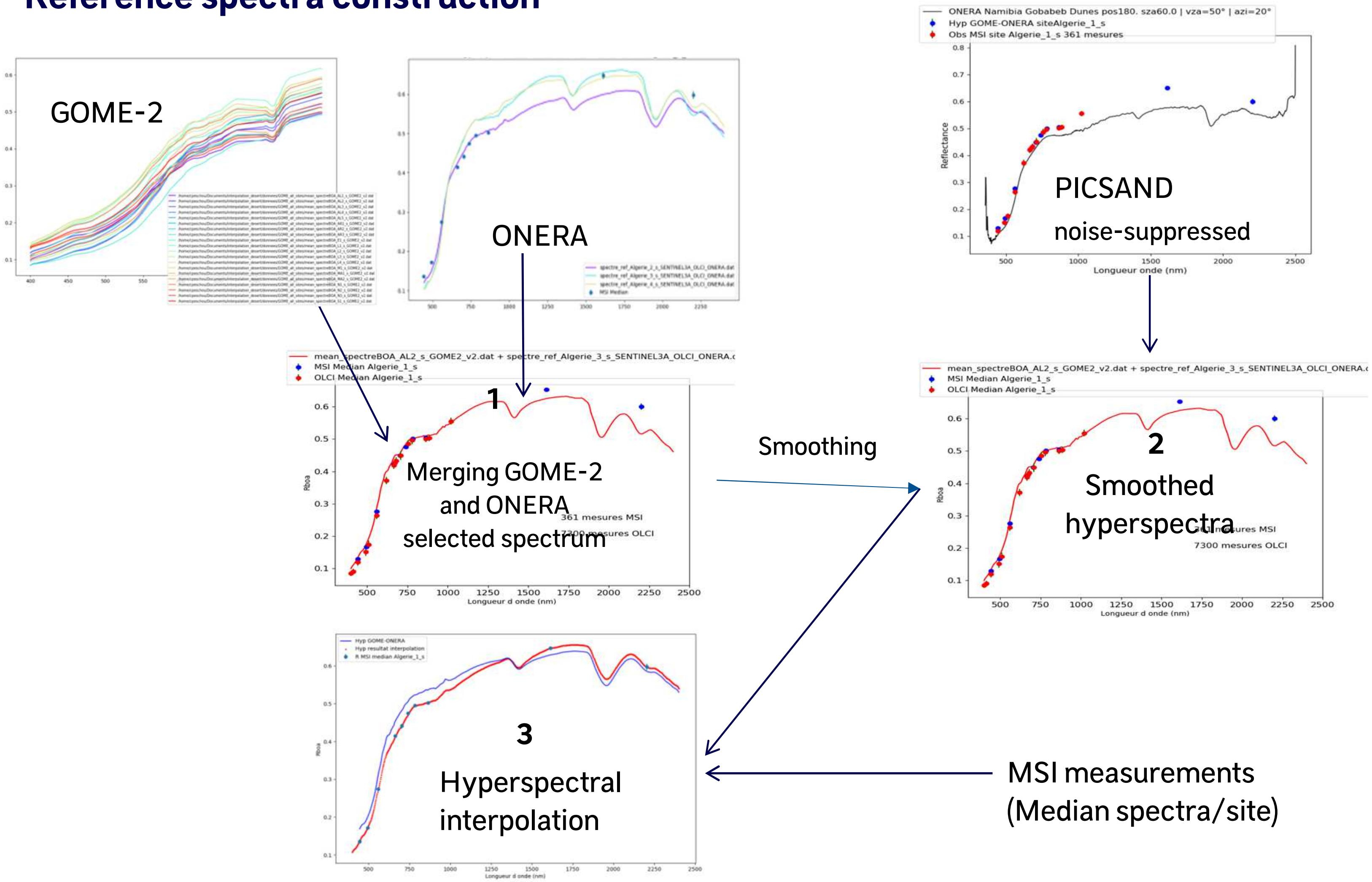
⇒ Visual preselection (spectrum shape, noise, spectral range)

CALIBRATION METHOD BASED ON PICS (WARM DESERTS)

cnes

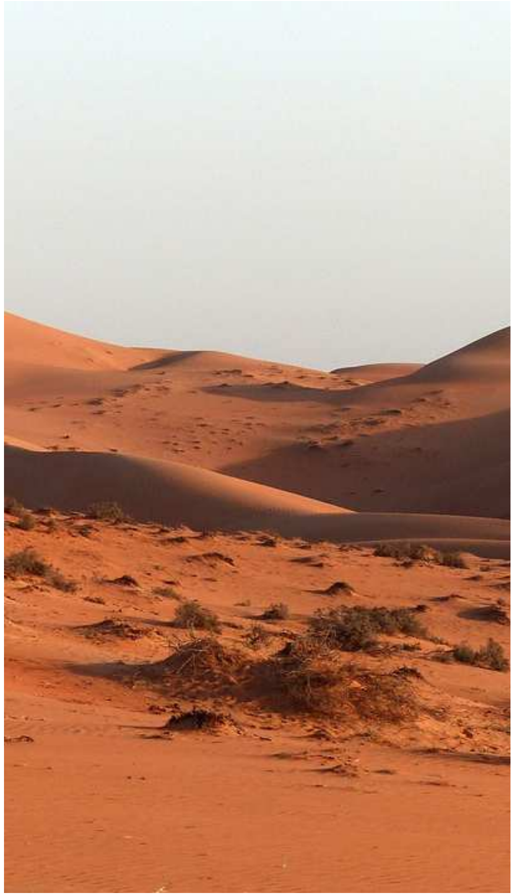
Reference spectra construction

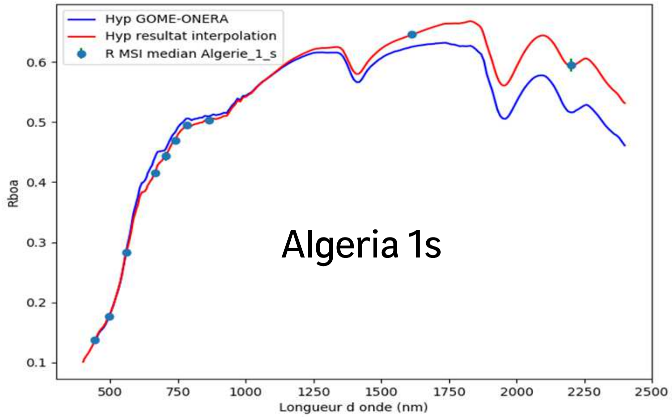


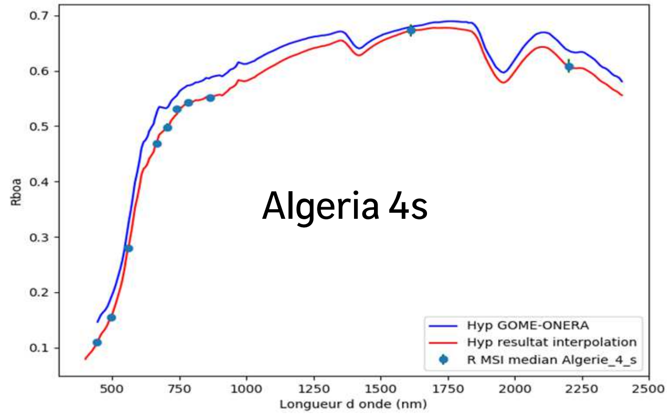


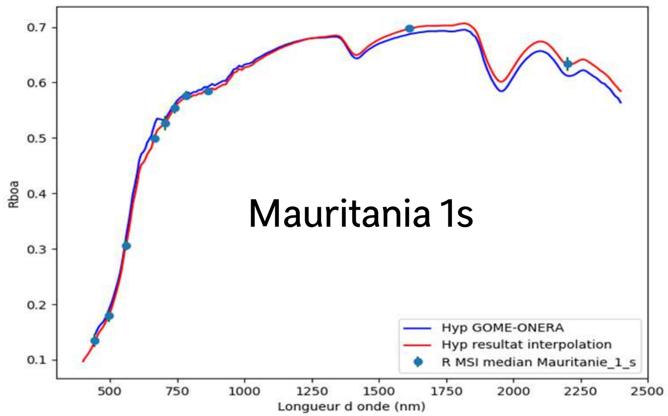
cnes

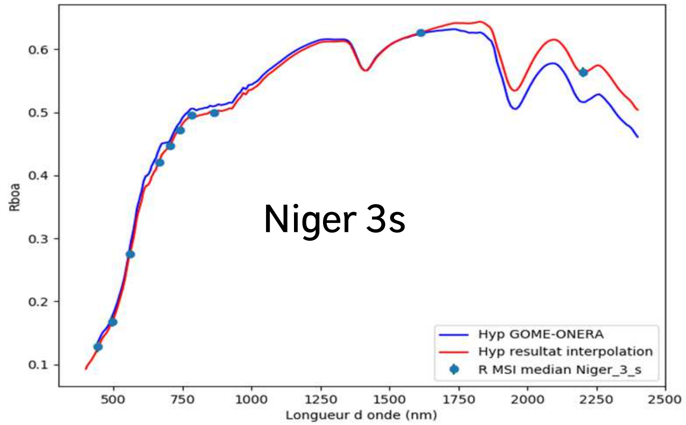
Hyperspectral interpolation of MSI measurements using **GOME-ONERA** reference spectra





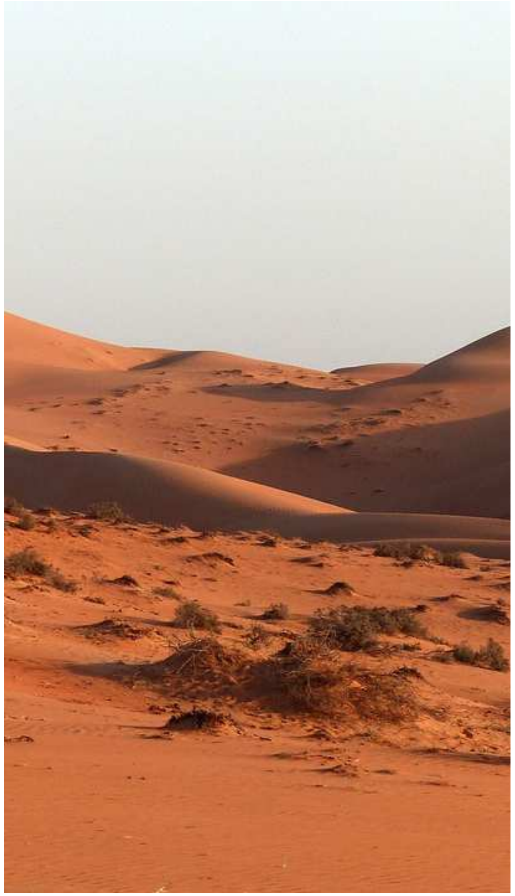


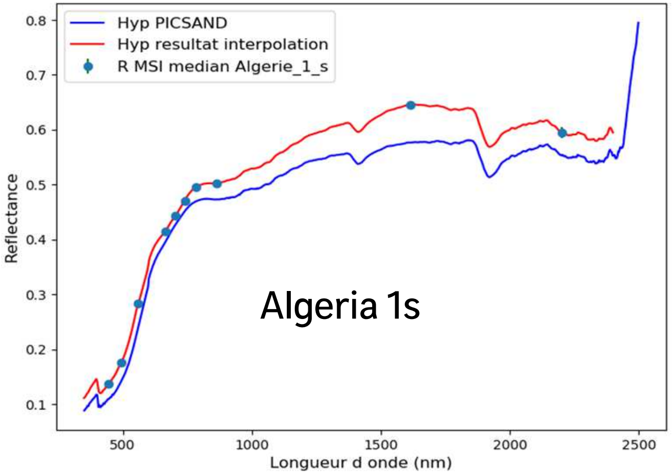


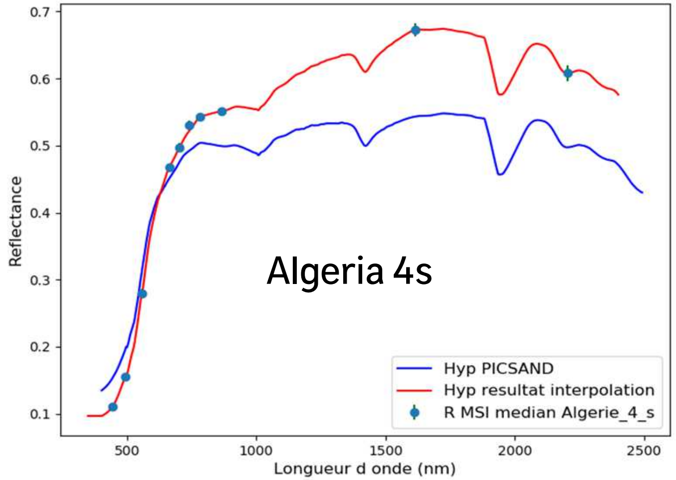


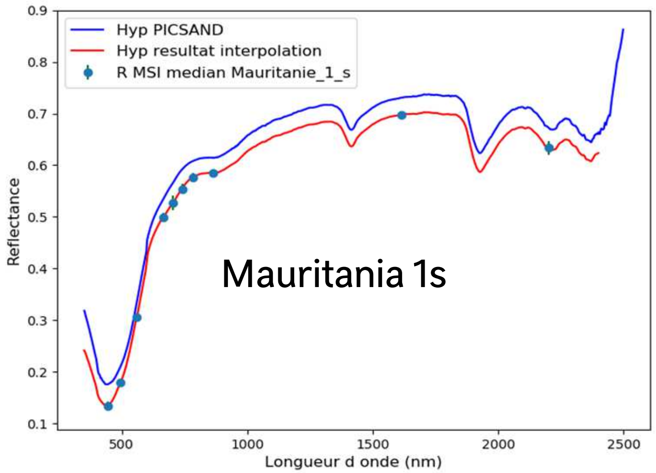
CALIBRATION METHOD BASED ON PICS (WARM DESERTS)

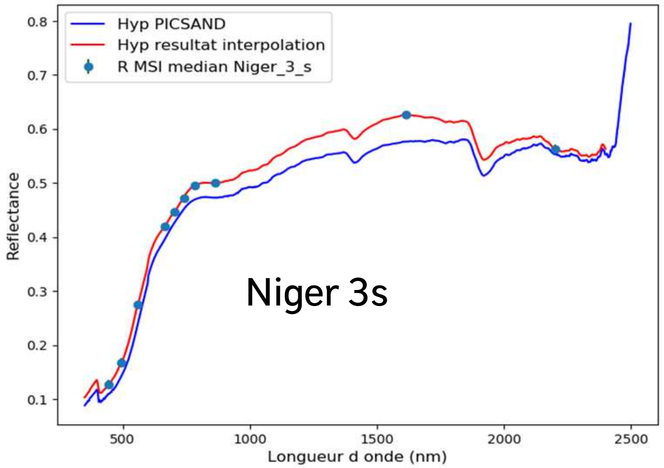
Hyperspectral interpolation of MSI measurements using **PICSAND** reference spectra



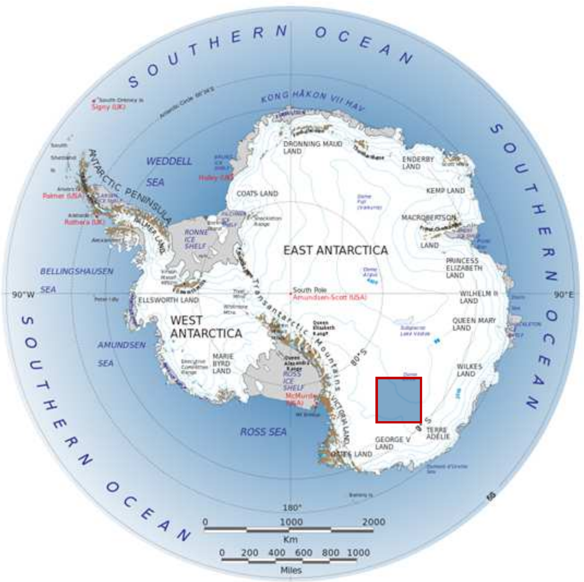








CALIBRATION METHOD BASED ON PICS (COLD DESERTS)



Approximative location of the Dome Concordia region

Hypothesis:

- **Arid and cold areas in Antarctica do not change over time.**
- **Two images acquired by different instruments, with the same solar and acquisition geometries, over such area can be compared after atmospheric corrections.**

Data used:

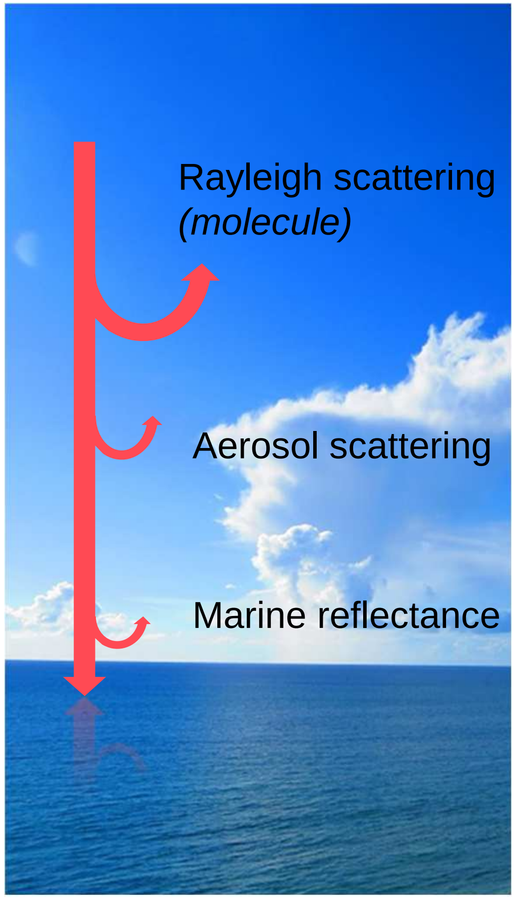
- **Mean reflectance over 4 Dome sites (~ 120 x 120 km², 2 different sites extracted on L1C products Dome-1, Dome-2, Dome-3, Dome-C).**

- **Exogenous data for the atmosphere which has a lower impact due to the high altitude of the sites (~3300 m)**

Calibration results:

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

RAYLEIGH SCATTERING METHOD



Hypothesis:

- **Over the oceans, for short wavelengths the TOA signal is mainly due to the Rayleigh scattering by the molecules of the atmosphere**
- **This scattering is accurately simulated**

Data used:

- **Mean reflectance over oligotrophic oceans with low aerosol content, no clouds, few wind (1 x 1 km² area extracted from L1C products).**
- **Exogenous data for the atmosphere and the marine reflectance**

Calibration results:

- **Absolute calibration coefficient $\Delta A_k = \frac{\rho_k^{measured}}{\rho_k^{simulated}}$ for short wavelengths (<750 nm).**

CALIBRATION METHOD BASED ON DEEP CONVECTIVE CLOUDS

Hypothesis:

- **Reflectance of DCCs is spectrally well-known for VNIR wavelengths**

Data used:

- **Mean reflectance over DCC (1 x 1 km², extracted from L1C products)**
- **Exogenous data for the atmosphere**

Calibration results:

- **Inter-band calibration coefficient** $\Delta A_k = \frac{\rho_k^{measured}}{\rho_k^{simulated}}$ **for VNIR bands using the red band as a reference for the simulation.**

CALIBRATION METHOD BASED ON THE GLINT

Hypothesis:

- **Specular reflection over oceans is well-known**

Data used:

- **Mean reflectance over sun glint area**
- **Exogenous data for the atmosphere**
- **Use of a reference band to compute the wind speed**
- **Use of an other viewing direction when available to assess the AOT**
- **Use of a climatology to compute the ocean refectance**

Calibration results:

- **Inter-band calibration coefficient $\Delta A_k = \frac{\rho_k^{measured}}{\rho_k^{simulated}}$ for VNIR bands using the red band as a reference for the simulation.**

CALIBRATION METHOD BASED ON THE MOON

Hypothesis:

- **ROLO model corrected by CNES to simulate the moon reflectance**

$$\rho_{ROLO\ corrected}(\lambda) = b(\lambda) * \rho_{ROLO}(\lambda) * \sum_{k=0}^{9} a_k\, g^k$$

Spectral correction / Stars

Phase angle correction / PLEIADES

Data used:

- **Mean reflectance over moon disk**
- **Viewing and sun geometry in a selenographic reference frame**

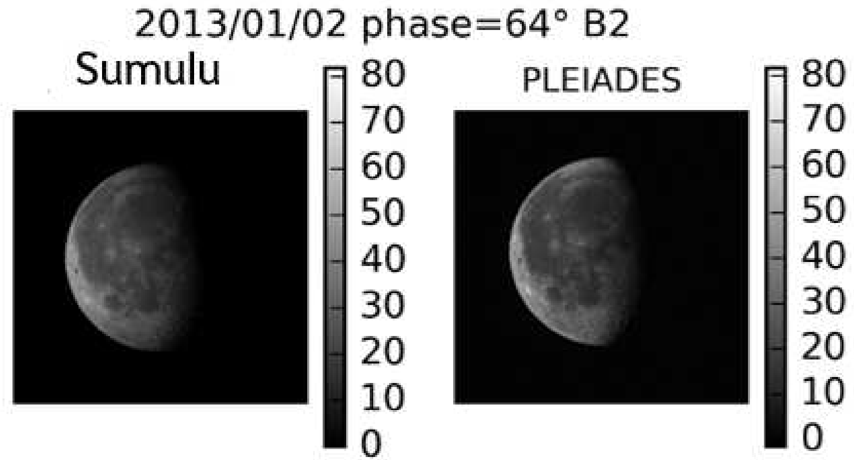
Calibration results:

- **Calibration coefficient** $\Delta A_k = \frac{\rho_k^{measured}}{\rho_k^{simulated}}$ **for VNIR bands (model correction optimal for PLEIADES spectral range, spectral extrapolation for SWIR bands)**

Moon Calibration - VNIR

Development of SUMULU : a simulator to generate synthetic « realistic » radiometric images of the Moon to perform different aspects of radiometric calibration (absolute, linearity, non uniformity, straylight, MTF…)

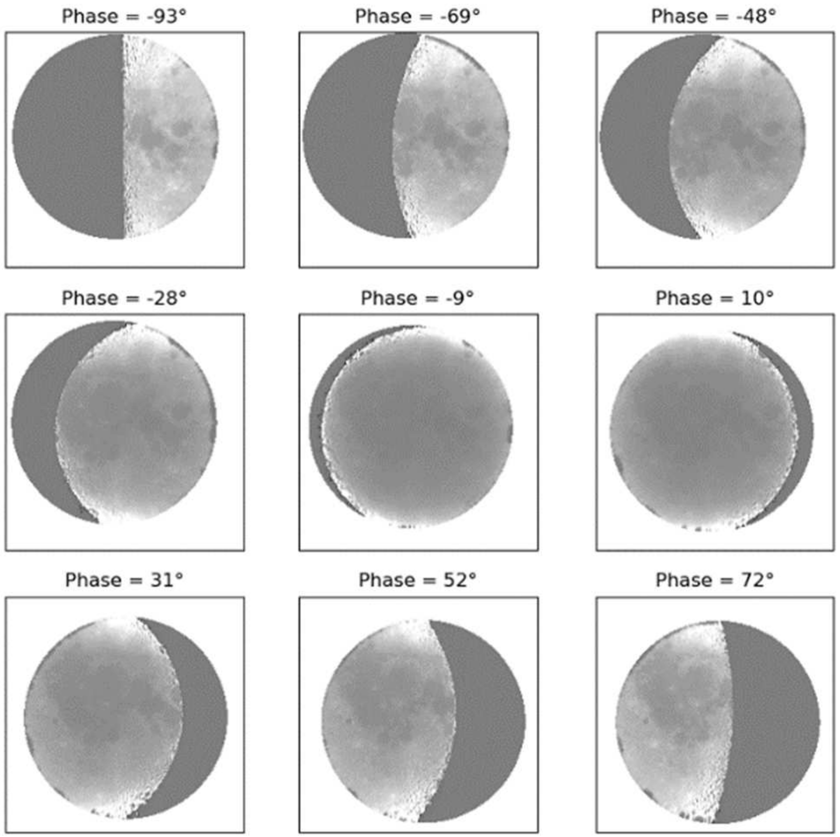
Albedo map + lunar DEM (LOLA) not sufficient



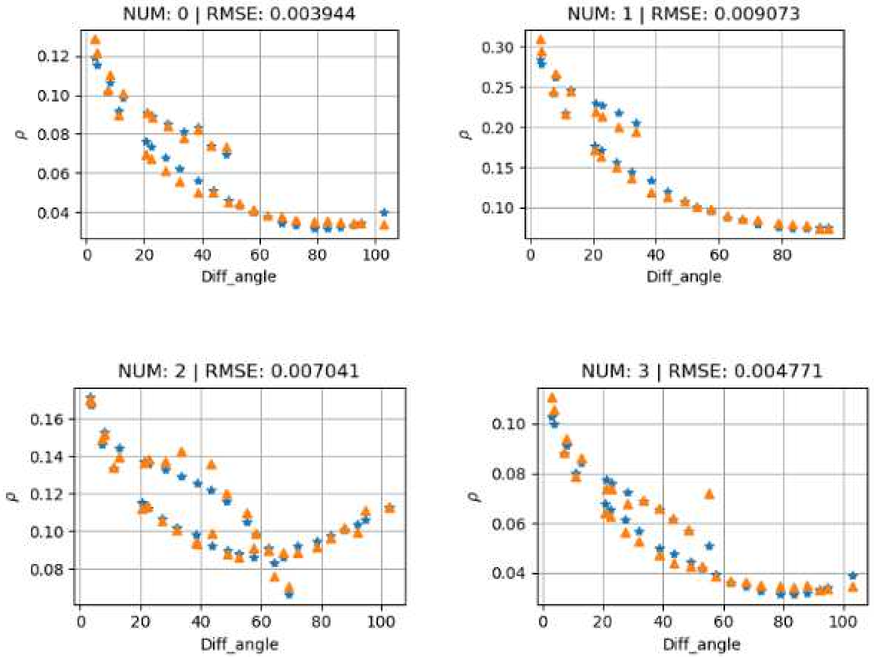
To improve the simulation

- « Selenoprojection » of the PLEIADES archive (several complete moon cycles observed, 1250 images)
  →Geolocation accuracy after geometric refining: ~1px XS (4µrad) ~1.5km on the Moon
- Computation of VZA, VAA, SZA, SAA and conversion to reflectance
- BRDF fit at pixel level (on-going)

Moon Calibration - VNIR



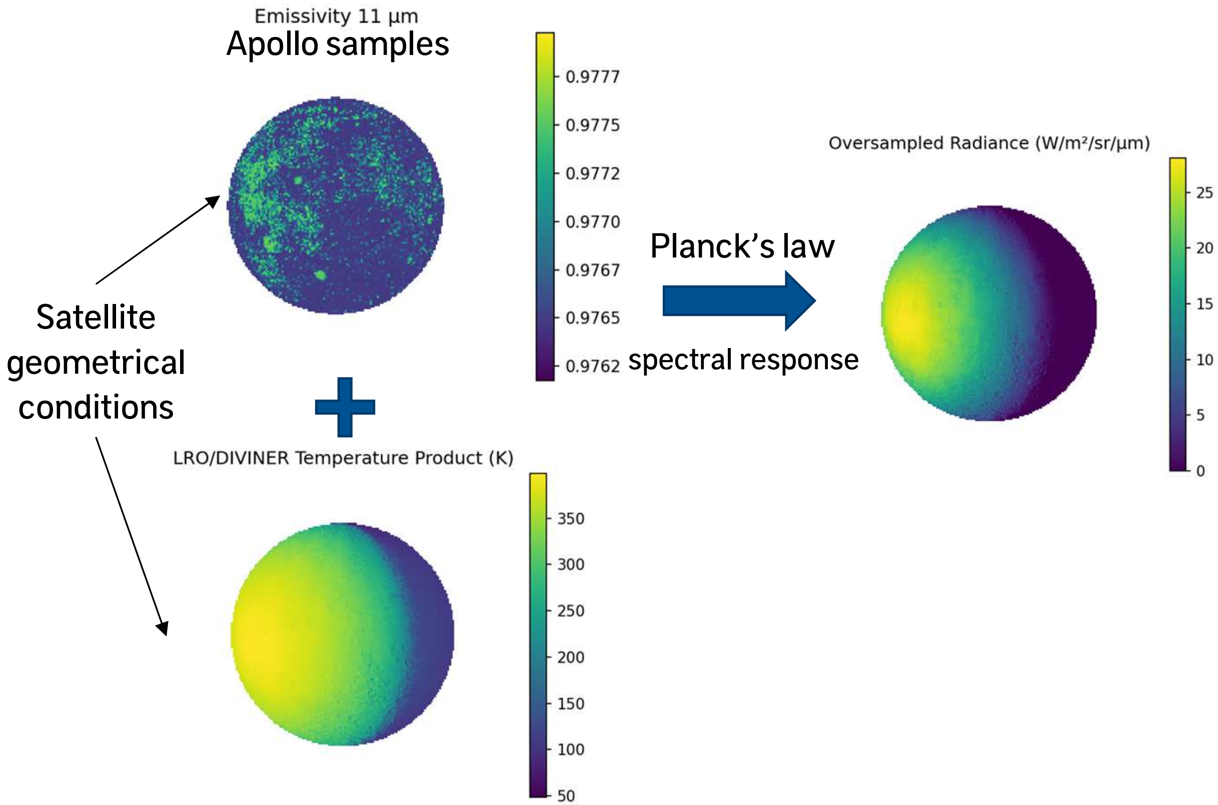
Orthorectified reflectance images from PLEIADES



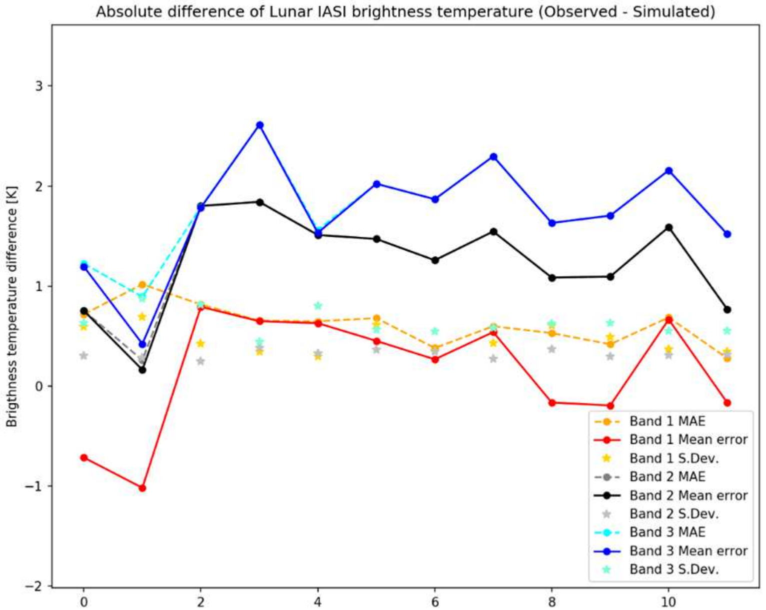
Exemple of BRDF (Jacquemoud) fits on several pixels

Moon Calibration - TIR

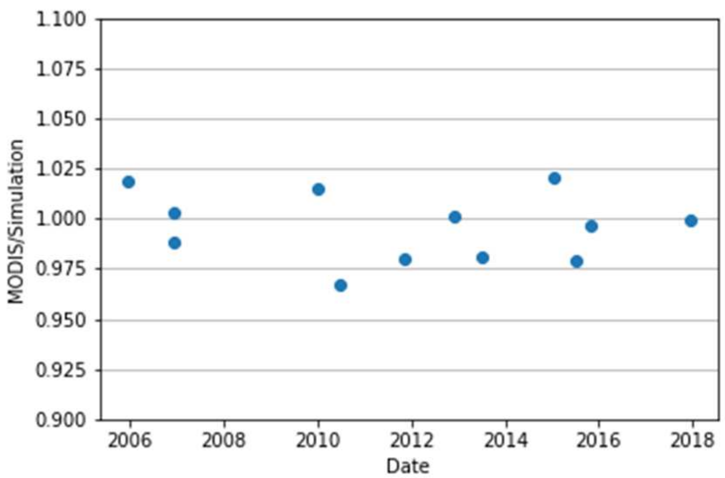
Development of a simulation of the TIR spectral irradiance integrated over the Moon
⟹ Can also be used to simulate images



Moon Calibration - TIR



Ratio of integrated irradiance over the Moon disk from MODIS B31 data and the simulation [Acknowledgment to Jack Xiong / NASA]



Improvements being investigated in 2022:

- Geometrical effects
  - localisation of the Moon within the IASI FOV
  - Directional emissivity
- Emissivity from Apollo samples (JHU-ECOSTRESS, Donaldson hanna et al 2016, Brown RELAB - PDS/CRISM)

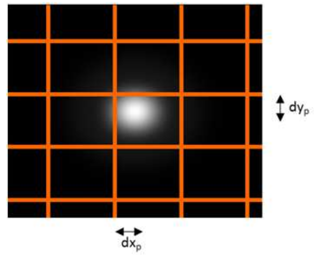
CALIBRATION METHOD BASED ON STARS

Hypothesis:

For each star p, the radiometric model, after normalization, in the Fourier domain can be written as:

$$FT^{p}_{l,m} = \sum_{u=0}^{s-1} \sum_{v=0}^{s-1} A_k \cdot L_k \cdot MTF_{l+u\cdot s, m+v\cdot s} \cdot ramp(dx_p, dy_p)_{l+u\cdot s, m+v\cdot s}$$

where:



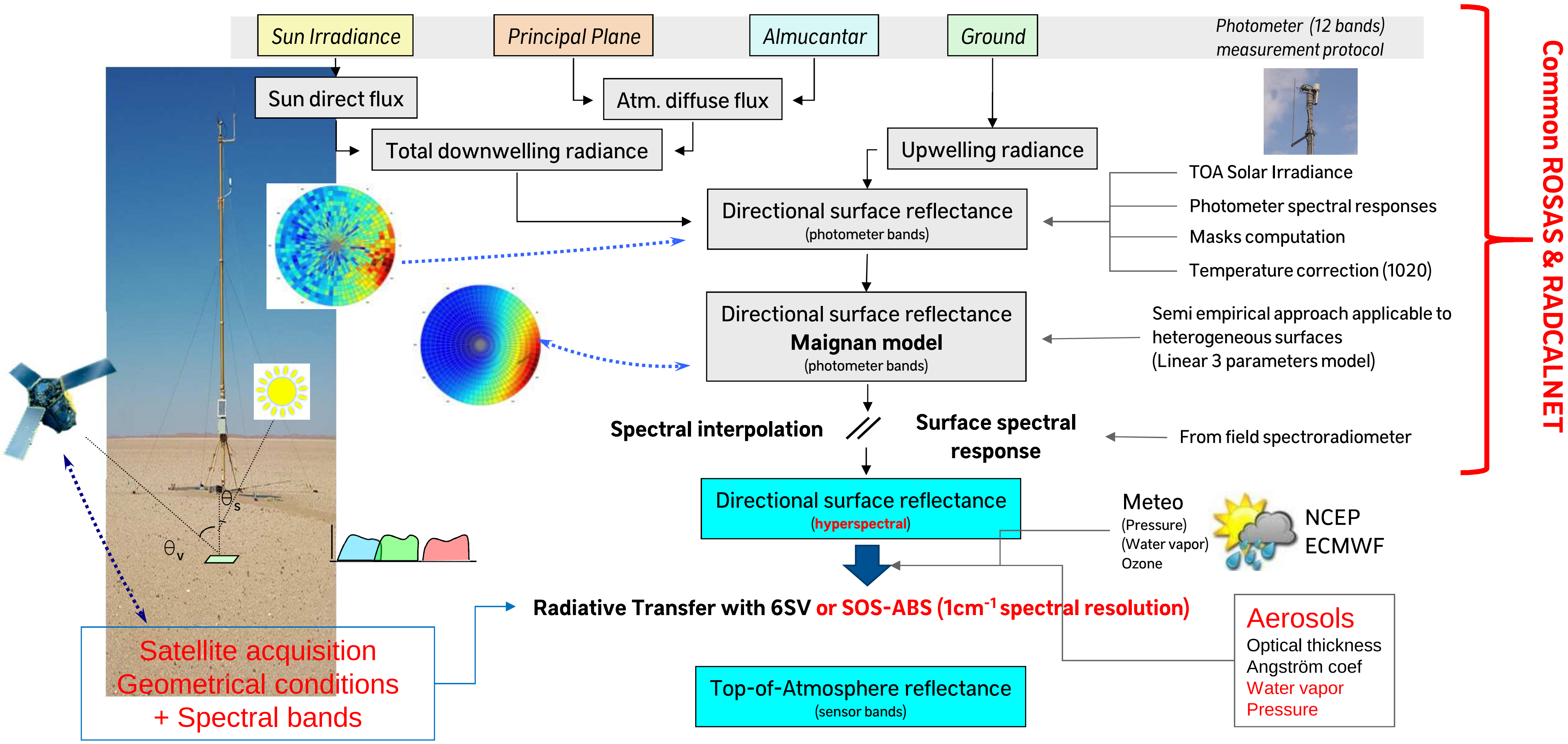
- **FT is the Fourier transform of p star image**
- **The aliasing contributions to the signal are summed**
- **MTF is the Modulation Transfer Function, which is normalized**
- **l,m are space frequencies along- and across-track**
- **s is the oversampling factor with regard to the Nyquist frequency**
- **ramp(dxp,dyp) is the phase ramp in Fourier space corresponding to a shift (dxp,dyp) for star p with regard to the sampling grid ⇒ pre-processing to determine (dxp,dyp) assuming that the MTF is real**
- **Ak is the absolute calibration coefficient**
- **Lk is the star's equivalent radiance – use of INDO_US library on going study to assess/use GAIA spectral irradiances**

⇒ Inversion of the radiometric model using a least mean squares method

Results:

- **Result(l,m) = A_k.MTF(l,m)**
- **A_k=Re[Result(0,0)]**
- **MTF(l,m)=Result(l,m)/A_k**

CALIBRATION METHOD BASED ON INSTRUMENTED SITES (ROSAS)

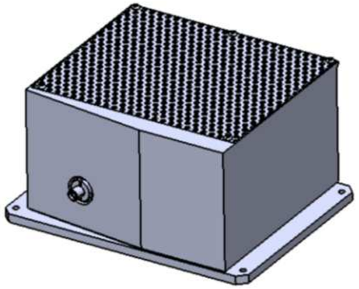
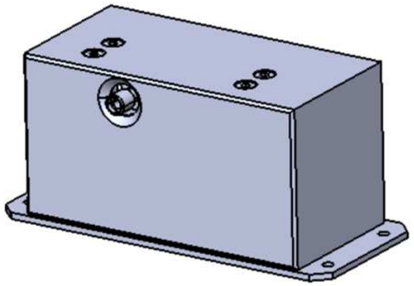
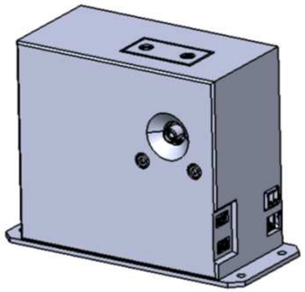


CALIBRATION METHOD BASED ON INSTRUMENTED SITES (ROSAS)

Hyperspectral evolutions

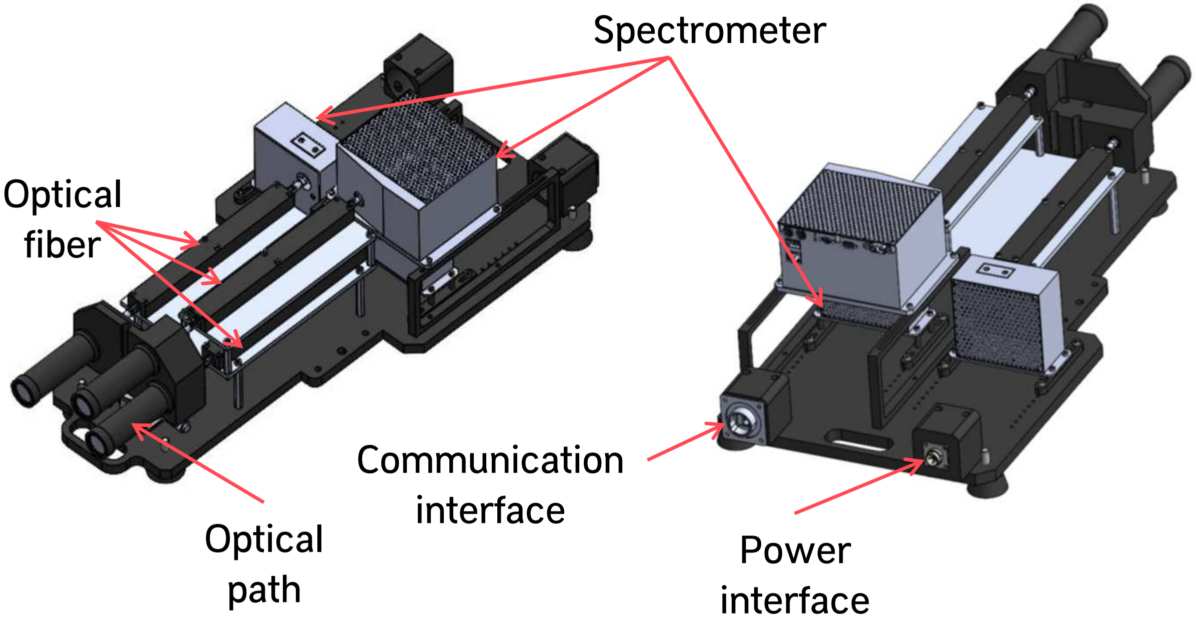
- Development of an hyperspectral instrument to improve in-situ measurements and to anticipate calibration needs of future hyperspectral missions
- Contract with CIMEL who assembles 3 OEM spectrometers made by HORIBA

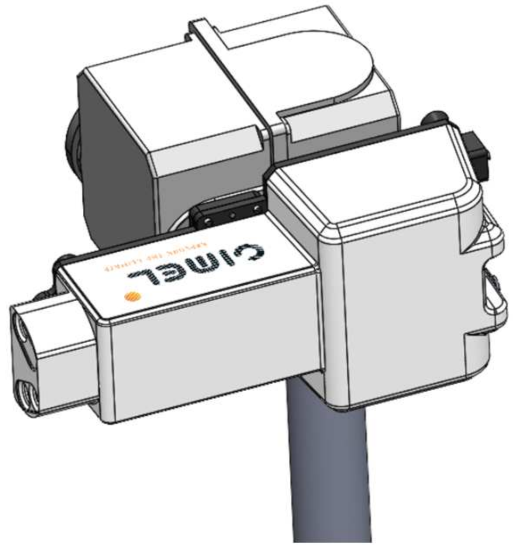
Item	HJY Specifications VNIR	HJY Specifications SWIR 1	HJY Specifications SWIR 2
Spectral range	350 – 1050 nm	1000 – 1700 nm	1600 – 2500 nm
Spectral resolution	< 2 nm	< 5 nm	< 10 nm
Sensor type	Si detector	InGaAs detector	InGaAs detector
Size	150 x 121,5 x 78,5 mm	115 x 52,5 x 52,3 mm	115 x 50 x 87 mm

Hyperspectral evolutions

- Laboratory mockup





Mockup coupled with the robot

CALIBRATION METHOD BASED ON INSTRUMENTED SITES (ROSAS)

cnes

Hyperspectral evolutions: planning

- Mockup and prototype development

Laboratory mockup assembly — Q2 2022

Mockup laboratory tests — Q3-2022

Mockup field calibration tests — Q4-2022

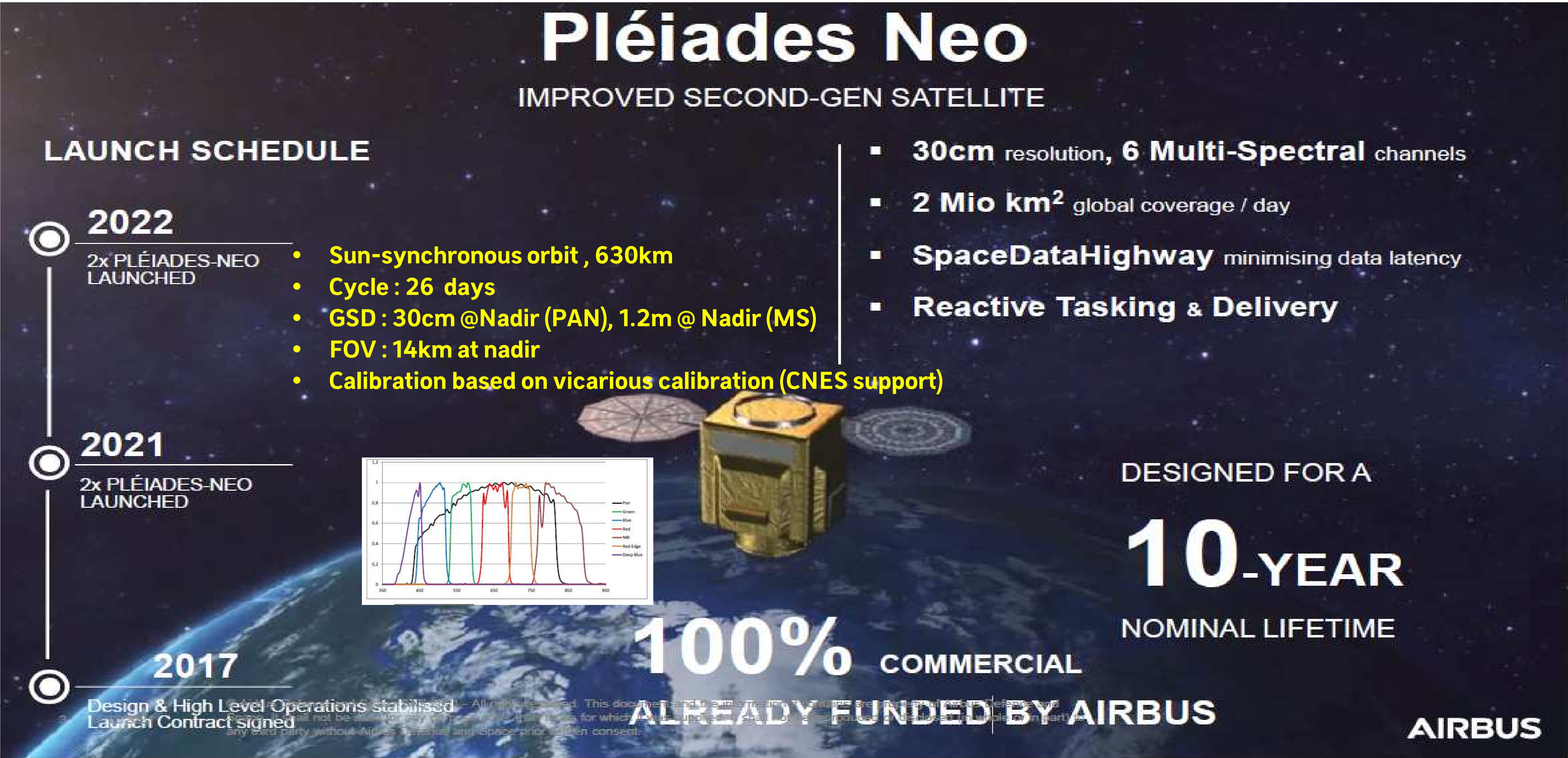
Prototype assembly — Q1-2023

Prototype laboratory tests — Q2/Q3-2023

Prototype field calibration tests — Q4-2023

Prototype deployment on La Crau site — Beginning of 2024

PNEO-3&4 CALIBRATION



- Sun-synchronous orbit , 630km
- Cycle : 26 days
- GSD : 30cm @Nadir (PAN), 1.2m @ Nadir (MS)
- FOV : 14km at nadir
- Calibration based on vicarious calibration (CNES support)

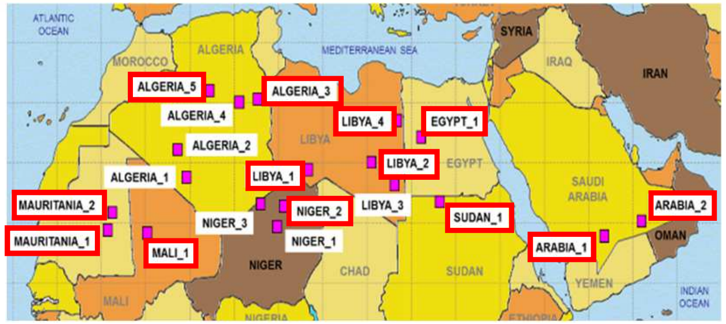
PNEO-3&4 CALIBRATION

V2020 AIRBUS

PNEO-3&4 CALIBRATION

Methods used:

PNEO-3 AND 4 CALIBATION BASED ON PICS

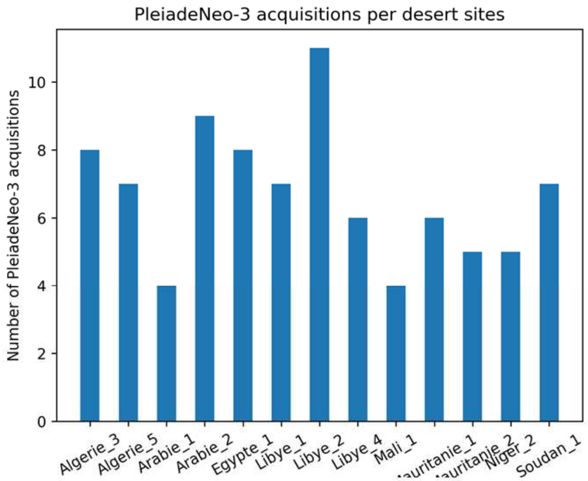


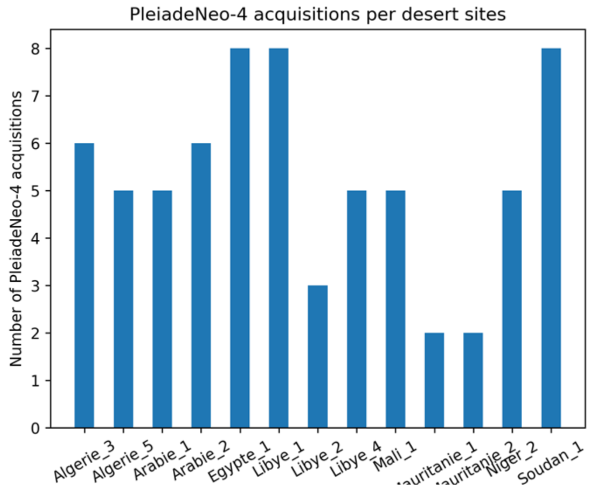
PNEO-3 data

- 13 sites
- 87 acquisitions
- Date : from mid-May to beginning of October 2021

PNEO-4 data

- 13 sites
- 68 acquisitions
- Date : from mid-September mid-December 2021





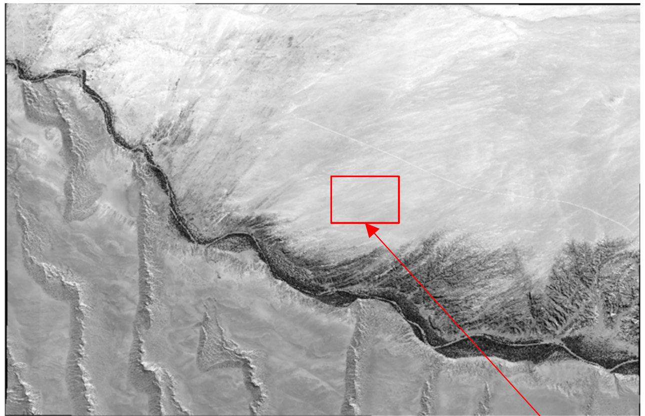
PNEO-3 AND 4 CALIBRATION BASED ON ROSAS/RadCalNet SITES

PNEO-3 data:

- 22 acquisitions on Gobabeb (6 cloudy / 5 cloudy day)
- 5 acquisitions on La Crau (3 cloudy / 2 cloudy day)
- Date : from 30/05/2021 to 02/10/2021
- 13 acquisitions on Gobabeb and 1 on La Crau are processed

PNEO-4 data:

- 5 acquisition on Gobabeb (1 cloudy day)
- 5 acquisition on La Crau
- Date : from 29/09/2021 to 06/12/2021
- 4 acquisitions on Gobabeb and 1 on La Crau are processed
- 4 La Crau products were acquired when there were issues with the station



PNEO3 – Gobabeb
21/08/2021

PNEO3 – La Crau
01/08/2021

ROSAS station location

PNEO-3 AND 4 CALIBRATION BASED ON STARS

cnes

PNEO-3 data:

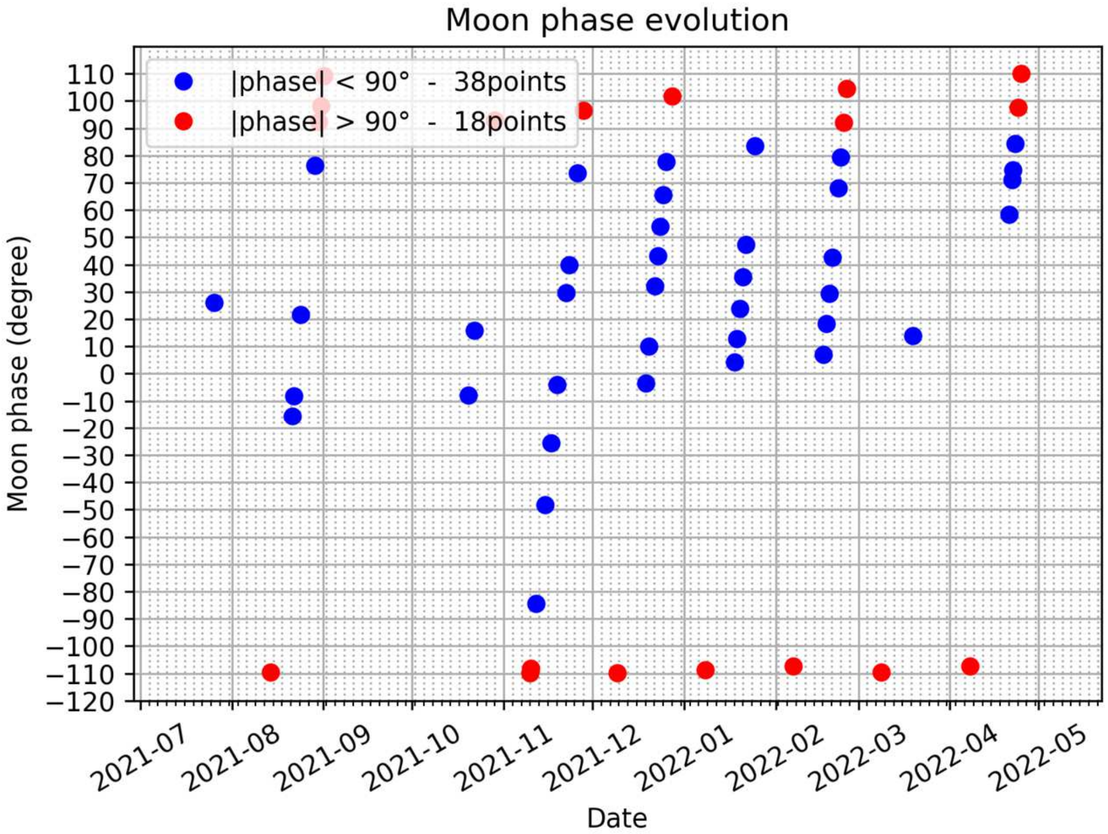
- 6 different stars have been acquired
- 70 acquisitions for XS bands
- 66 acquisitions for PAN band

PNEO-4 data:

- 7 different stars have been acquired
- 70 acquisitions for XS bands
- 64 acquisitions for PAN band

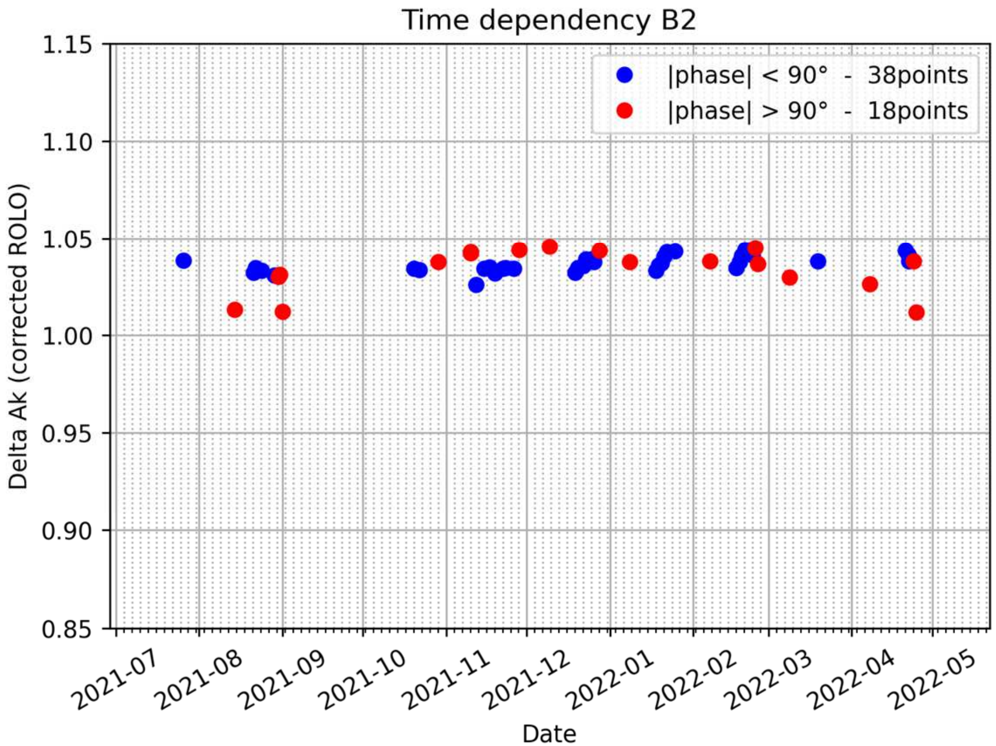
PNEO-3 data:

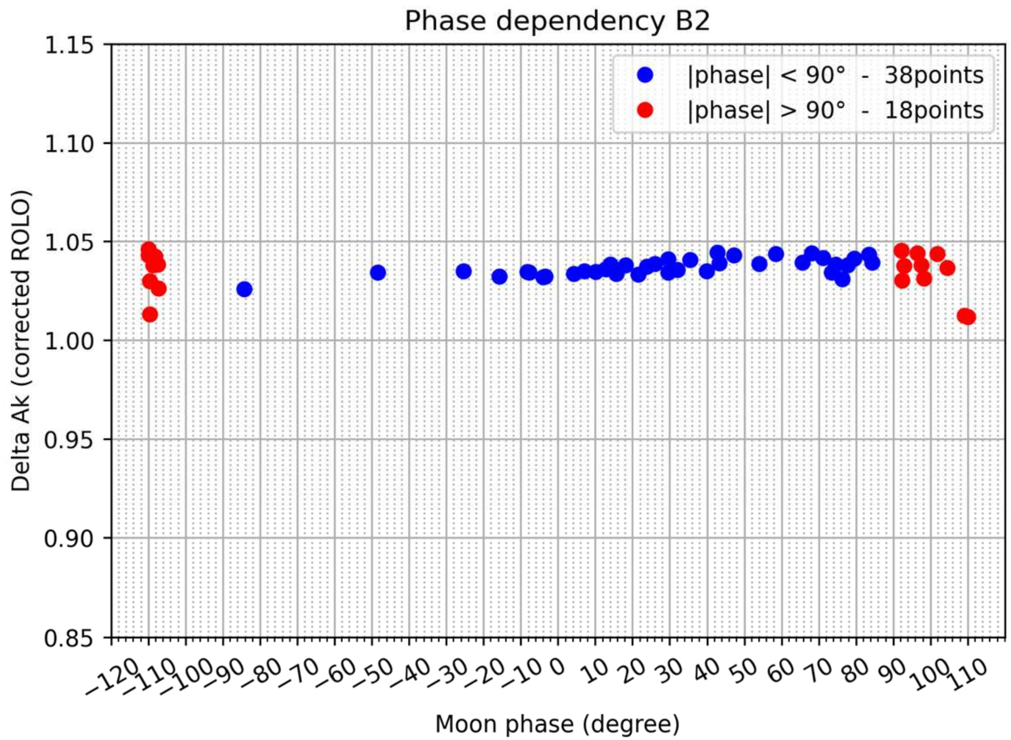
- 87 acquisitions
- Moon phase : [-110°,110°]
- Date : from July 2021 to April 2022 (9 Moon cycles)



PNEO-3 AND 4 CALIBRATION BASED ON THE MOON

PNEO-3 Results



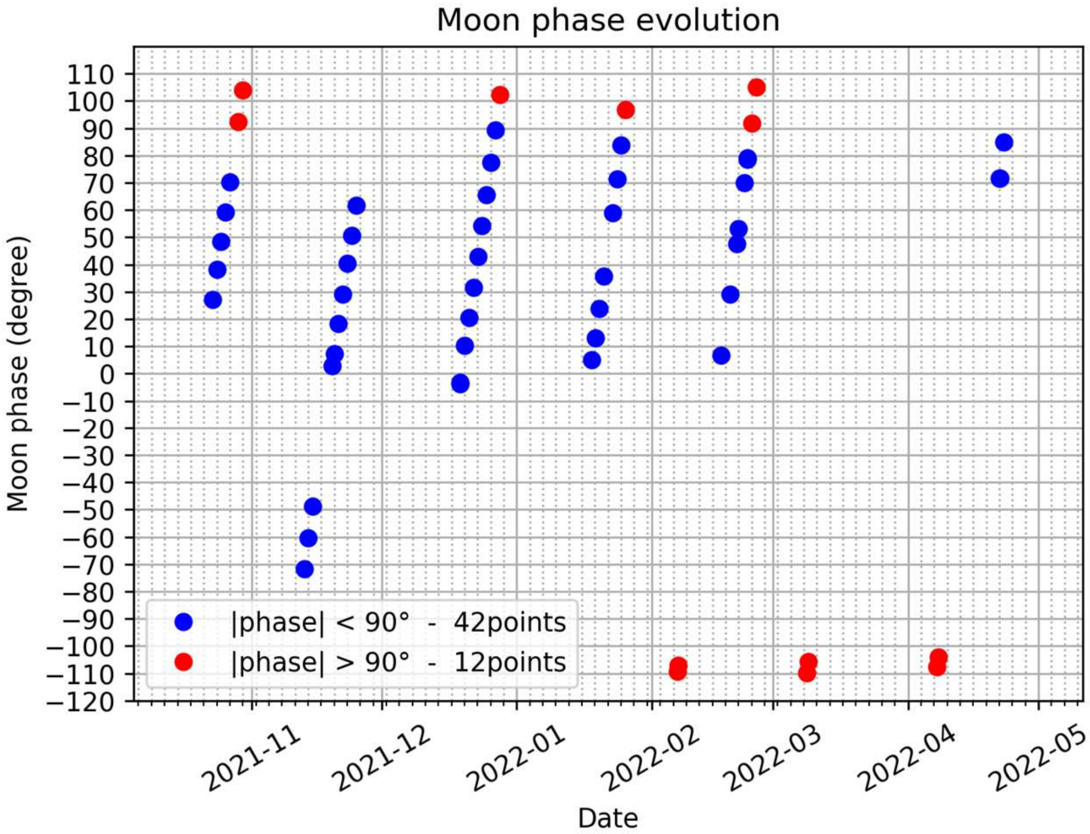


- Very weak noise on the measurements
- Slight variation of the calibration as a function of time (but less than one year)
- The residual dependency on the phase angle is very small

PNEO-3 AND 4 CALIBRATION BASED ON THE MOON

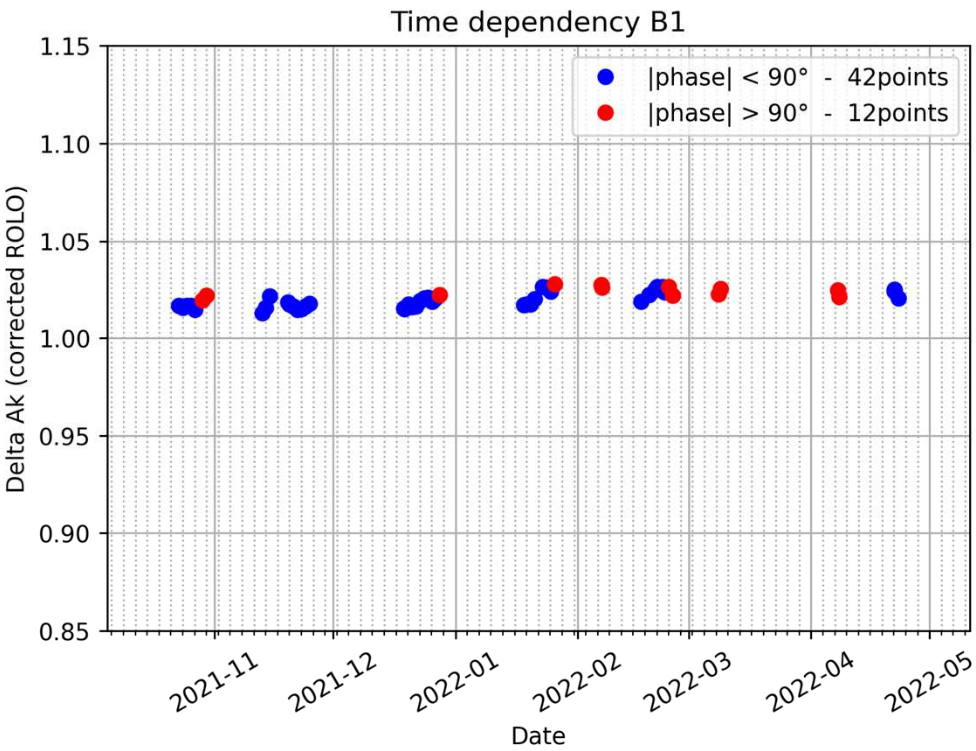
PNEO-4 data:

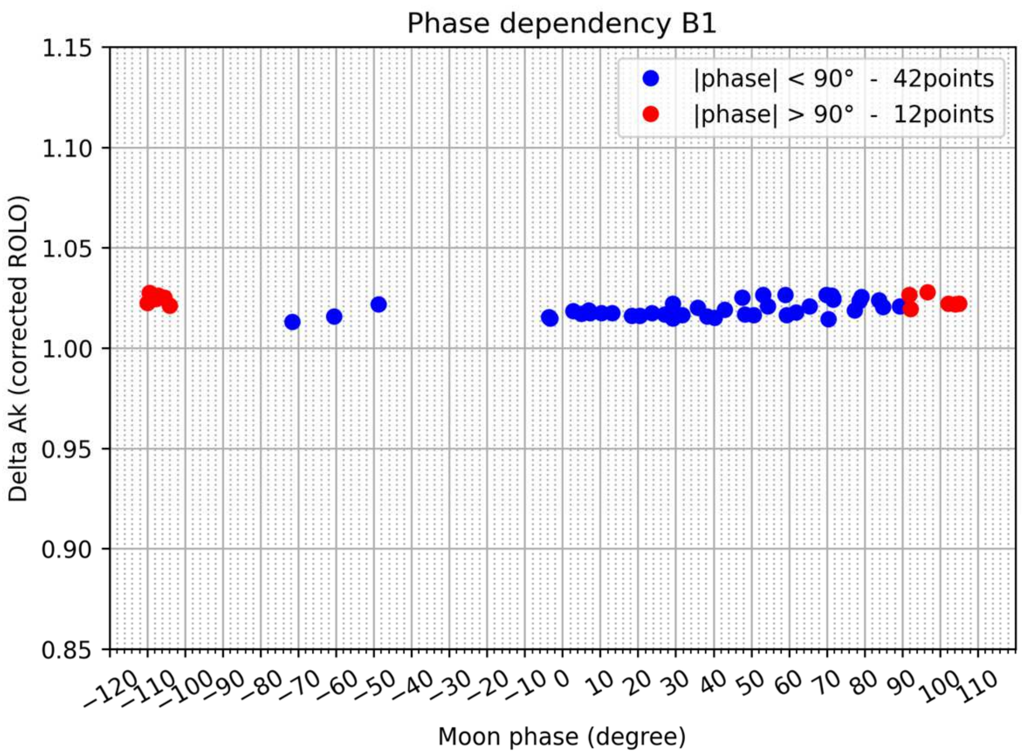
- 66 acquisitions
- Moon phase : [-110°,110°]
- Date : from October 2021 to April 2022 (7 Moon cycles)



PNEO-3 AND 4 CALIBRATION BASED ON THE MOON

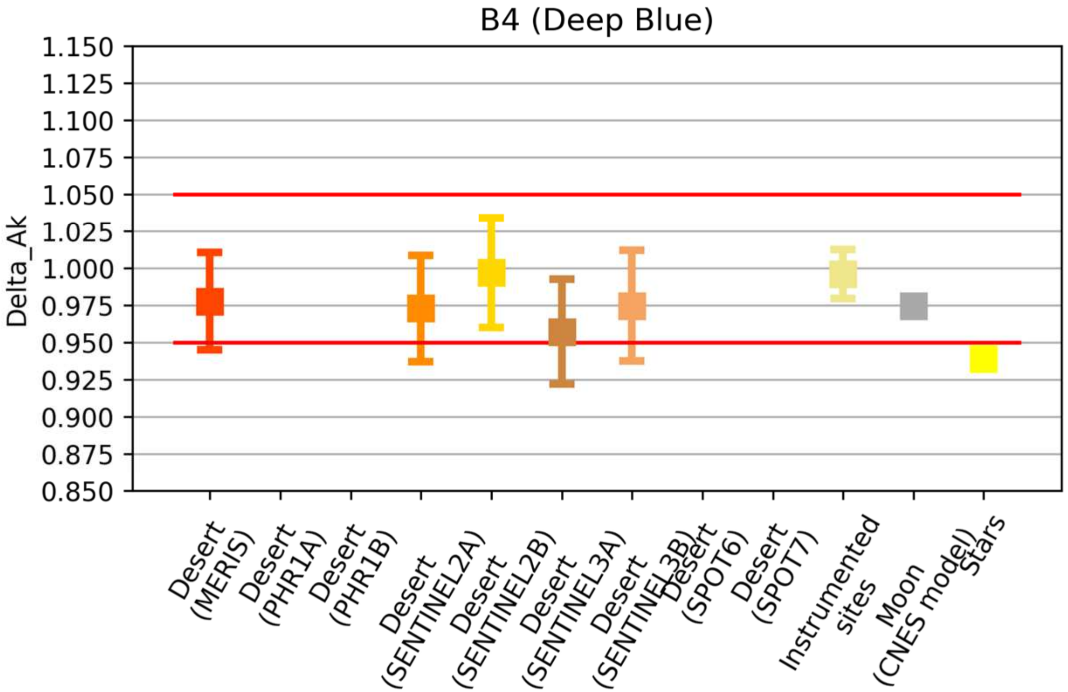
PNEO-4 Results

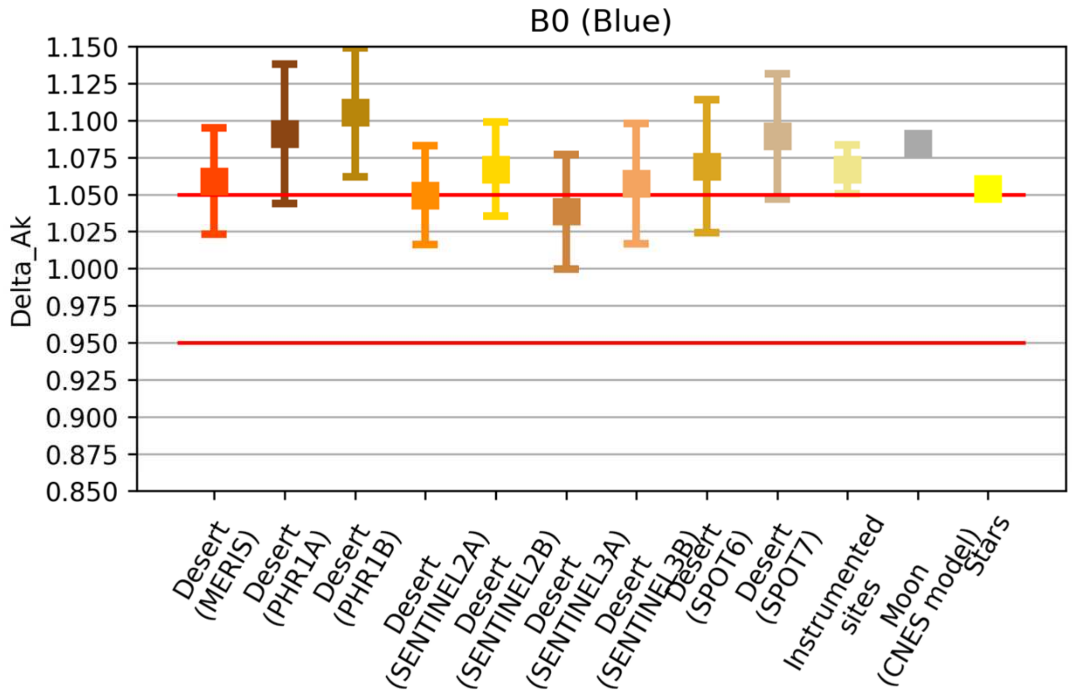




- Very weak noise on the measurements
- Slight variation of the calibration as a function of time (but less than one year of data)
- No dependency on the phase angle

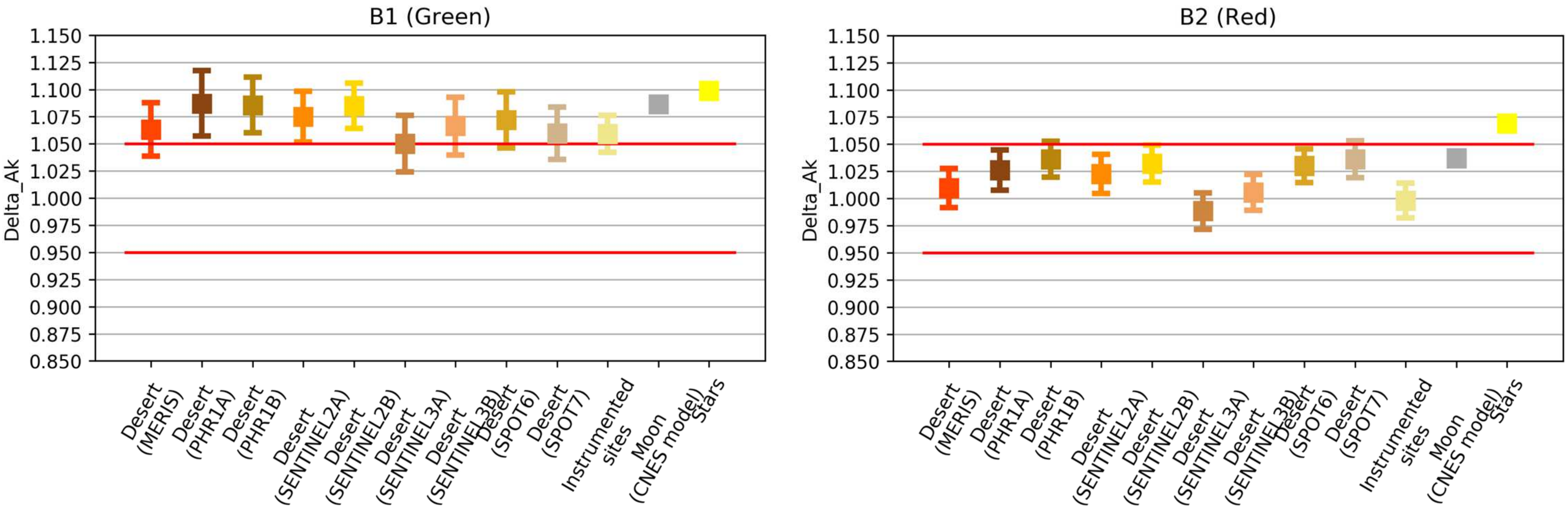
PNEO-3 CALIBRATION SYNTHESIS





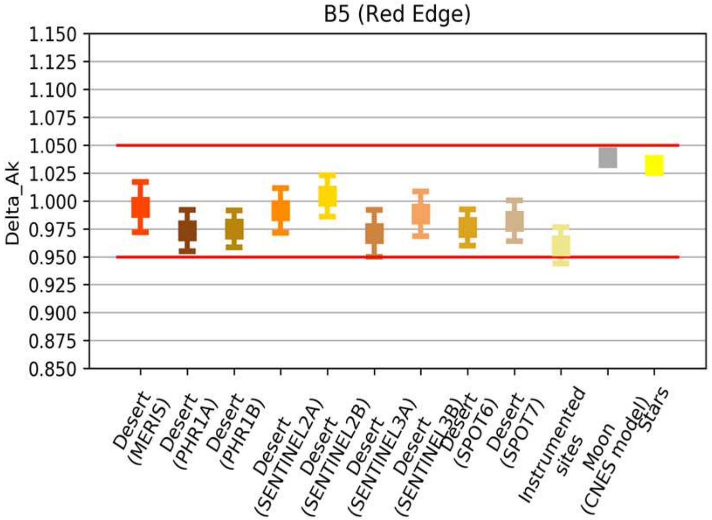
- Good consistency between the different methods
- Calibration reference for the routine phase: PICS/S3B

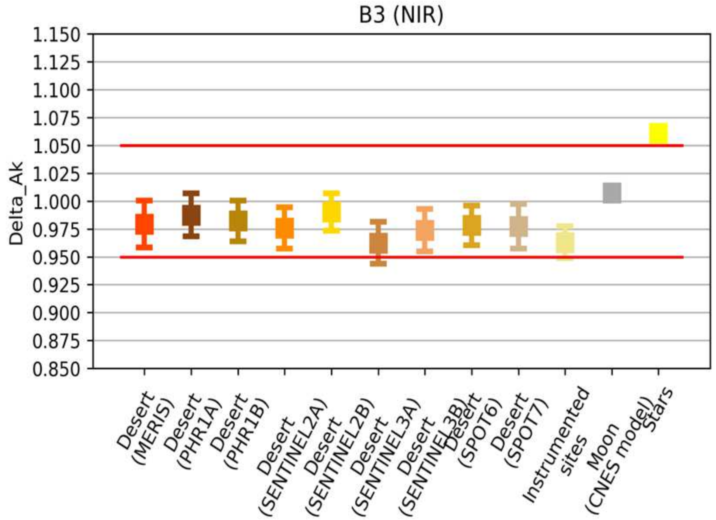
PNEO-3 CALIBRATION SYNTHESIS

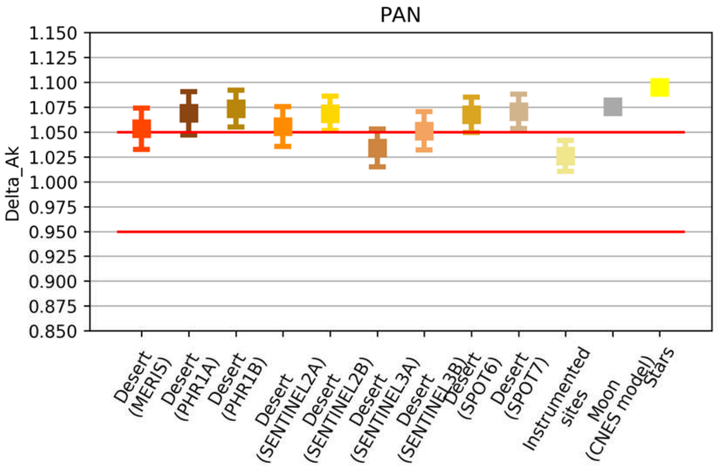


- Unexpected bias between results on Stars and Deserts acquisitions for B2

PNEO-3 CALIBRATION SYNTHESIS

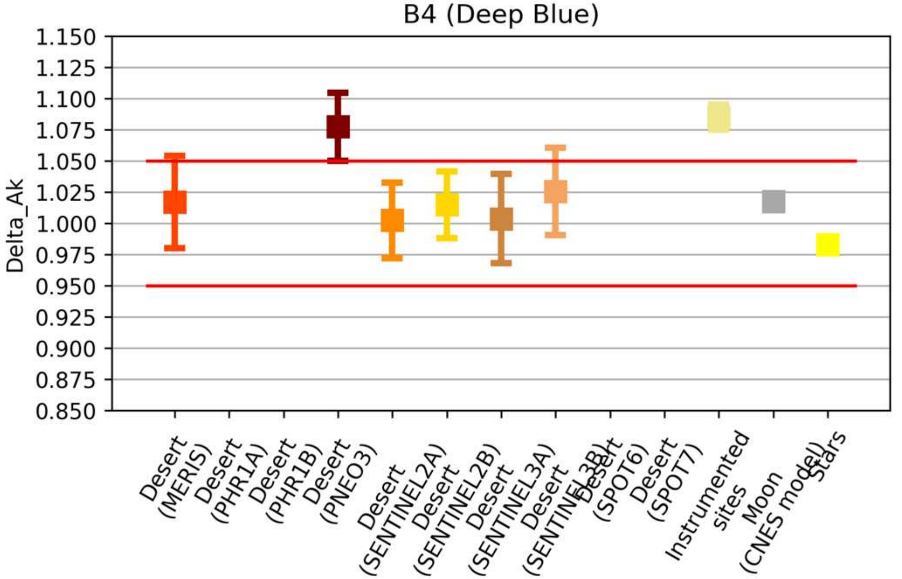


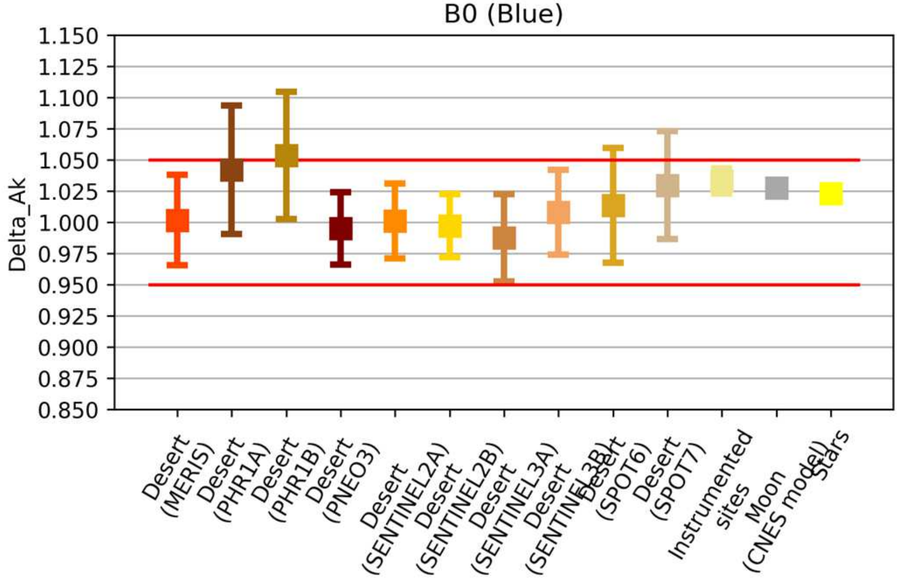




- Bias between results on Stars/Moon and Desert acquisitions

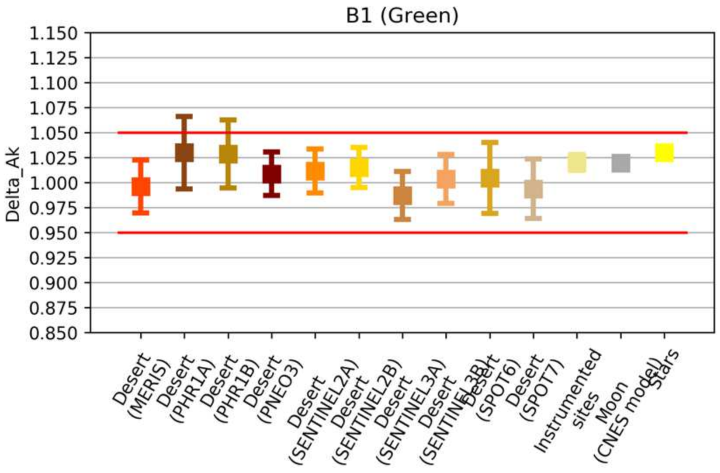
PNEO-4 CALIBRATION SYNTHESIS

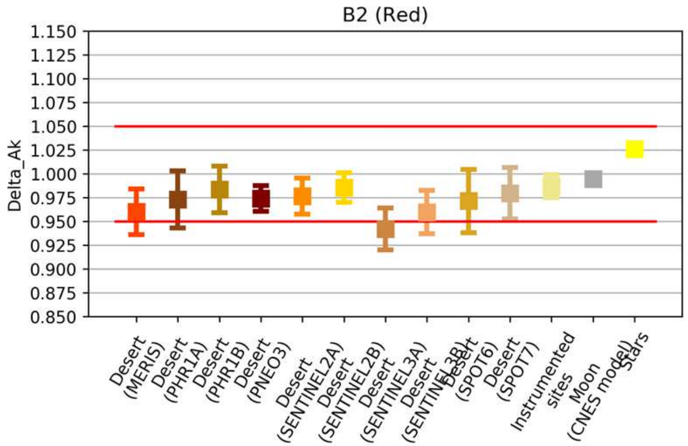


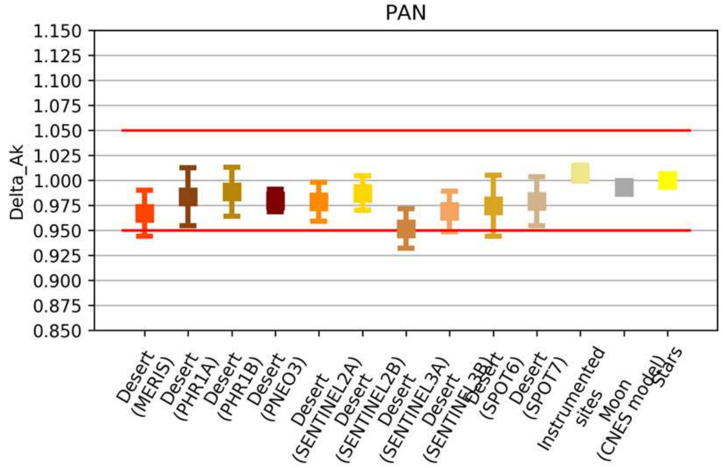


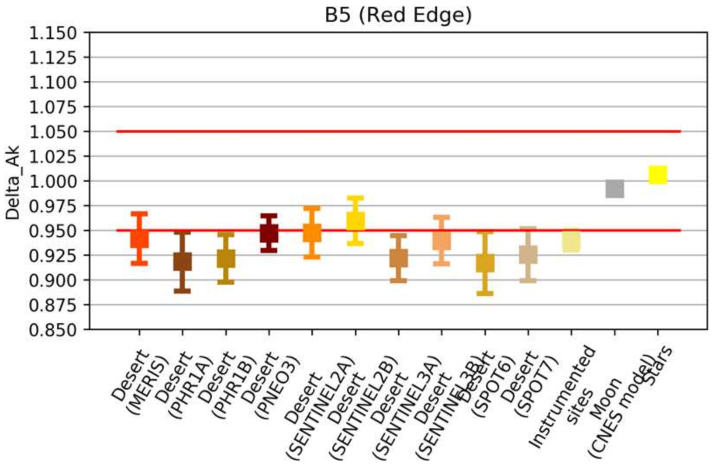
- Bias for PICS/PNEO-3 and ROSAS due to BOA reflectance extrapolation

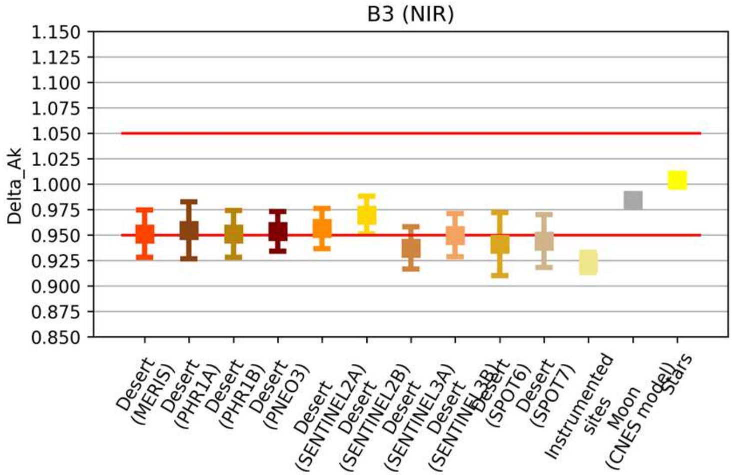
PNEO-4 CALIBRATION SYNTHESIS





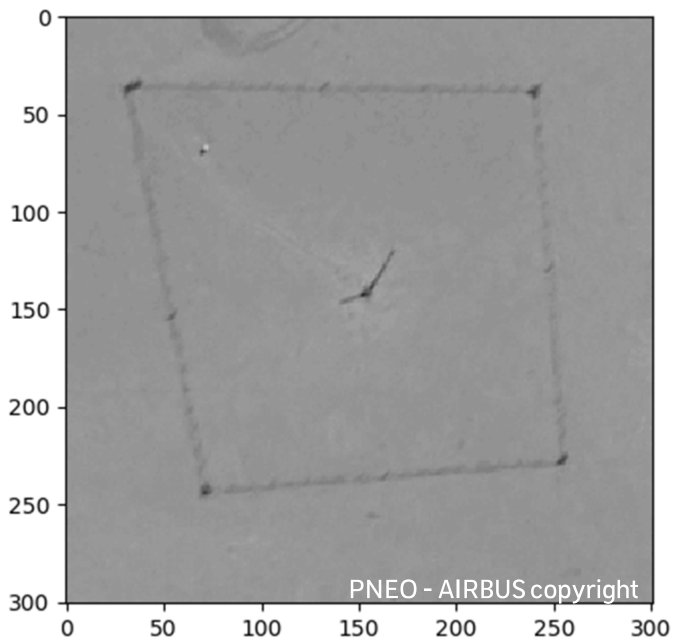






PNEO-3 AND 4 CALIBRATION: CONCLUSION

- Good global consistency of the different results, except for stars in some bands (investigation on going)
- On orbit calibration for routine phase based on PICS/S3B
- Multi-temporal calibration (drift monitoring) based on the moon



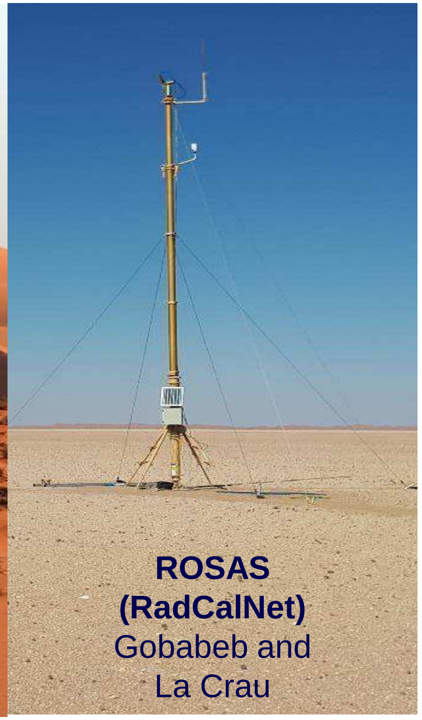
PRISMA CALIBRATION

PRISMA payload main characteristics

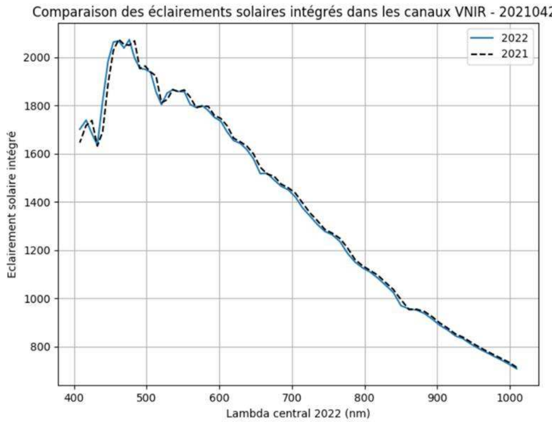
Orbit parameters	
Altitude	620 km (nominal)
Period	96 min
Repeat cycle	29 days (430 orbits)
Three mirrors anastigmatic telescope (TMA)	
Effective focal length	620 mm
Entrance Pupil diameter	210 mm
Swath / FOV	30 km / 2.77°
IFOV	48urad
F#	2.95
Hyperspectral sensor	
Spectral range	VNIR 400-1010 nm SWIR 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

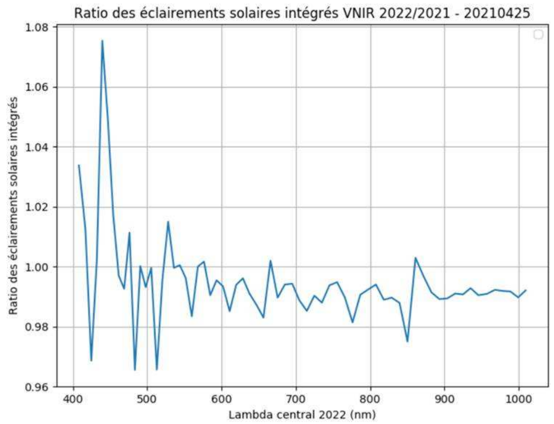
PRISMA CALIBRATION

Methods used :

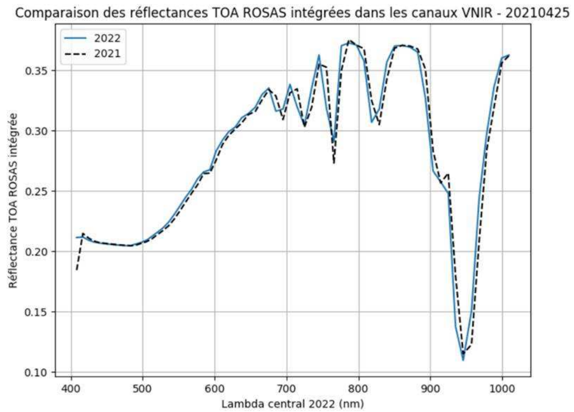


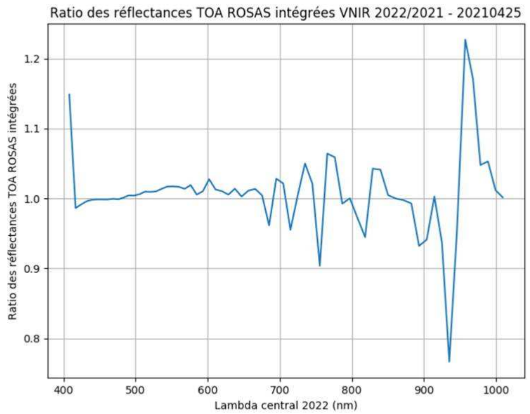
PRISMA CALIBRATION BASED ON ROSAS: IMPACT OF PRISMA SPECTRAL RESPONSES CHANGE





Comparison between the solar spectrum (Thuiller 2002) integrated in PRISMA VNIR bands before and after 2022 update (4nm spectral shift for VNIR bands) : more than 7% variation close to 420nm...



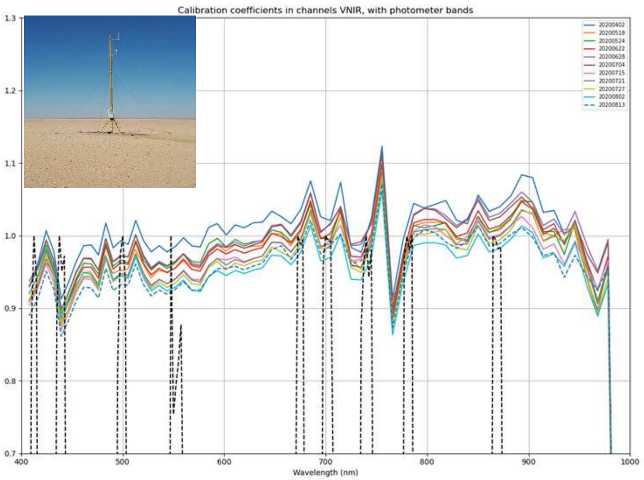


Impact of the spectral shift on PRISMA equivalent reflectance (Gobabeb product acquired on the 25/04/2021 – VNIR) ⇒ Stronger variation around absorption features

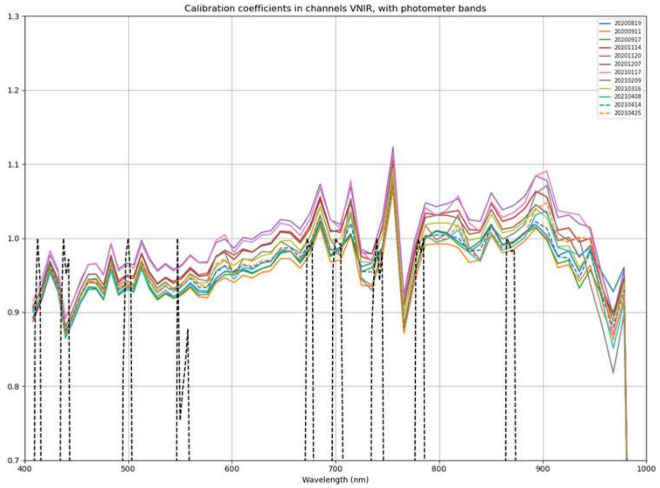
PRISMA CALIBRATION BASED ON ROSAS: DETAILED RESULTS FOR GOBABEB

- 46 (over 63) Gobabeb acquisitions used for calibration processing

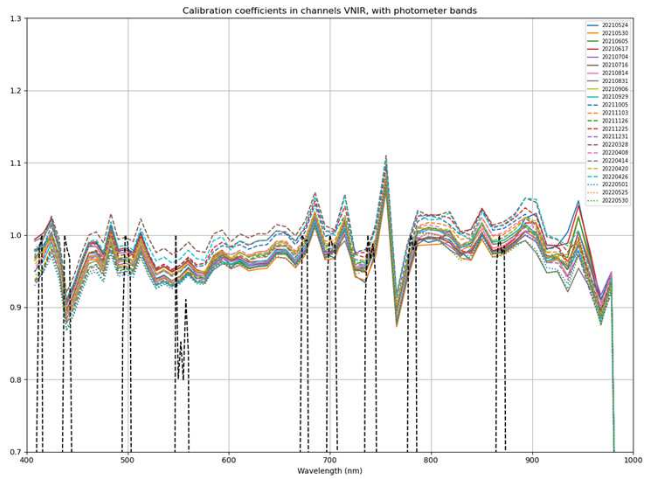
Period 1 (march 2020– 18 August 2020)

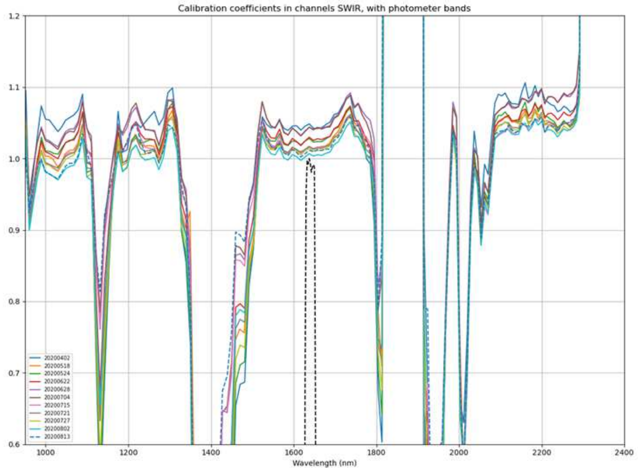


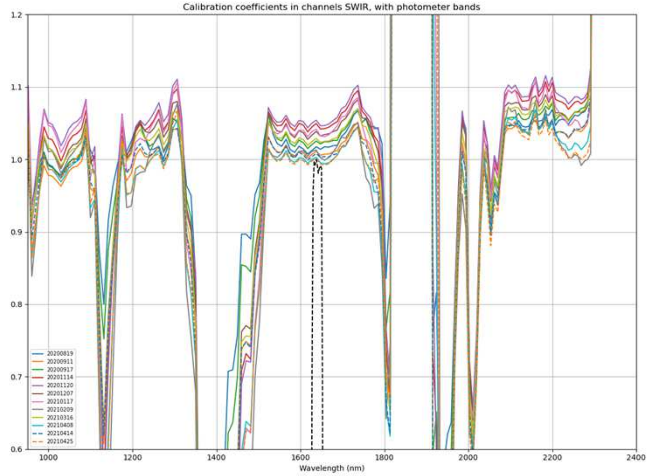
Period 2 (18 August 2020 – 6 May 2021)

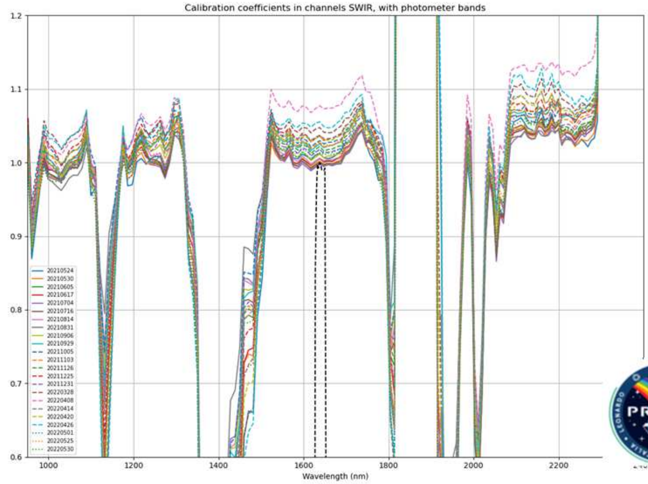


Period 3 (6 May 2021 – Today)

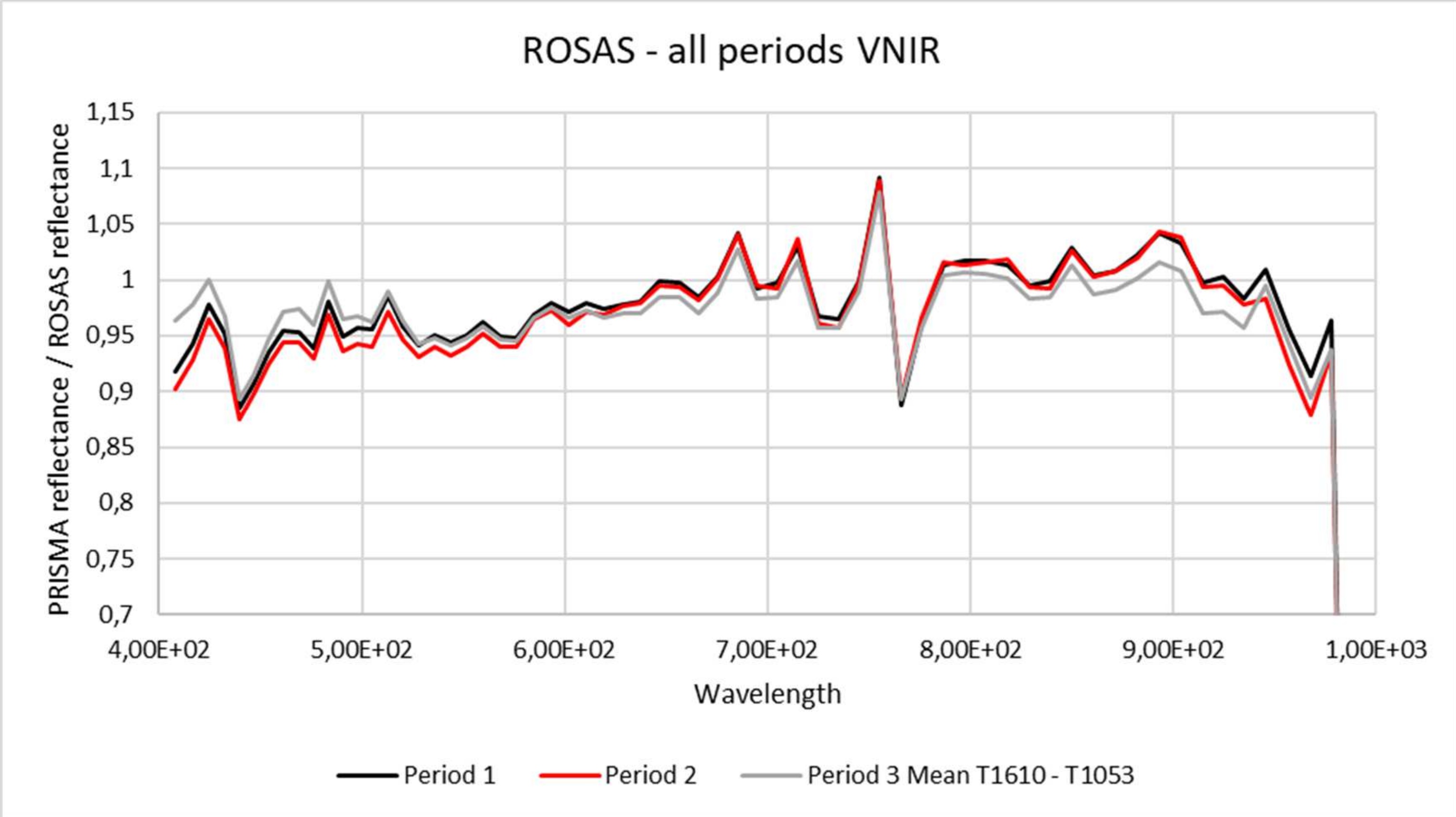






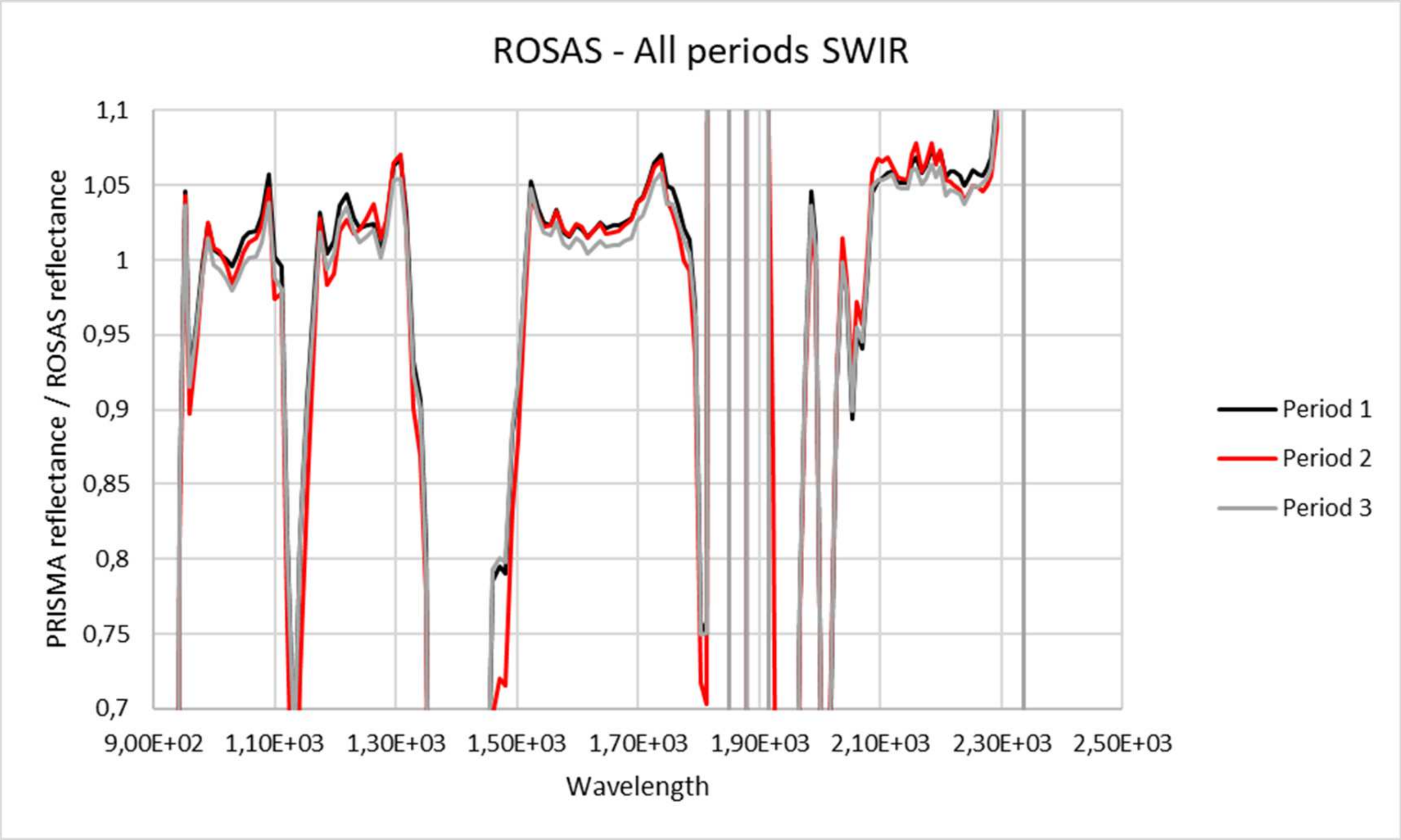


PRISMA CALIBRATION BASED ON ROSAS: MEAN RESULTS FOR GOBABEB



- **No significant variation between period 1 and 2**
- **3% max variation between period 1-2 and 3 for NIR bands**
- **Significant variation between PRISMA current official calibration and all these new measurements for short wavelengths (<650nm)**

PRISMA CALIBRATION BASED ON ROSAS: MEAN RESULTS FOR GOBABEB



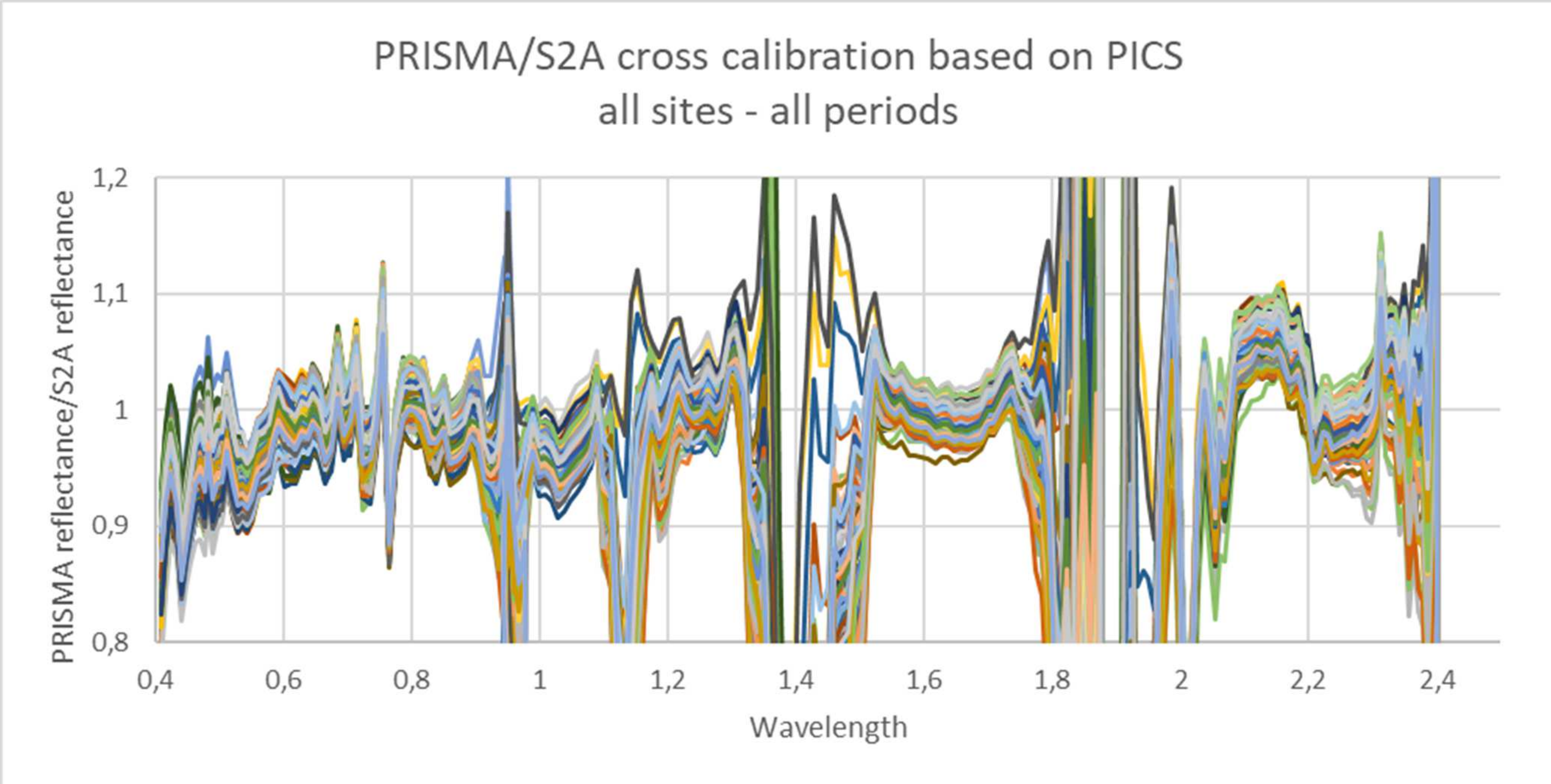
- **Good stability between period 1, 2 and 3 for SWIR bands (1% variation between period 1-2 and 3)**

PRISMA CALIBRATION BASED ON PICS: PROCESSED DATA

	Number of PRISMA images	Number of PRISMA images used for calibration	Number of PRISMA images used for calibration Period 1	Number of PRISMA images used for calibration Period 2	Number of PRISMA images used for calibration Period 3	Number of PRISMA/S2A couples of images processed for calibration	Number of PRISMA/S3B couples of images processed for calibration
Algeria1	2	1	0	0	1	3	0
Algeria2	27	9	0	3	6	124	11
Algeria3	23	18	1	6	11	400	11
Algeria4	23	9	2	3	4	517	1
Egypt1	11	6	0	0	6	94	11
Libya1	19	11	0	3	8	124	14
Libya2	28	17	1	4	12	405	22
Libya3	27	17	4	3	10	576	42
Libya4	20	9	2	3	4	223	17
Niger2	16	16	0	2	14	294	38
Niger3	24	20	2	4	14	327	26
Sudan	33	27	4	7	16	1176	52
Total	253	160	16	38	106	4263	245

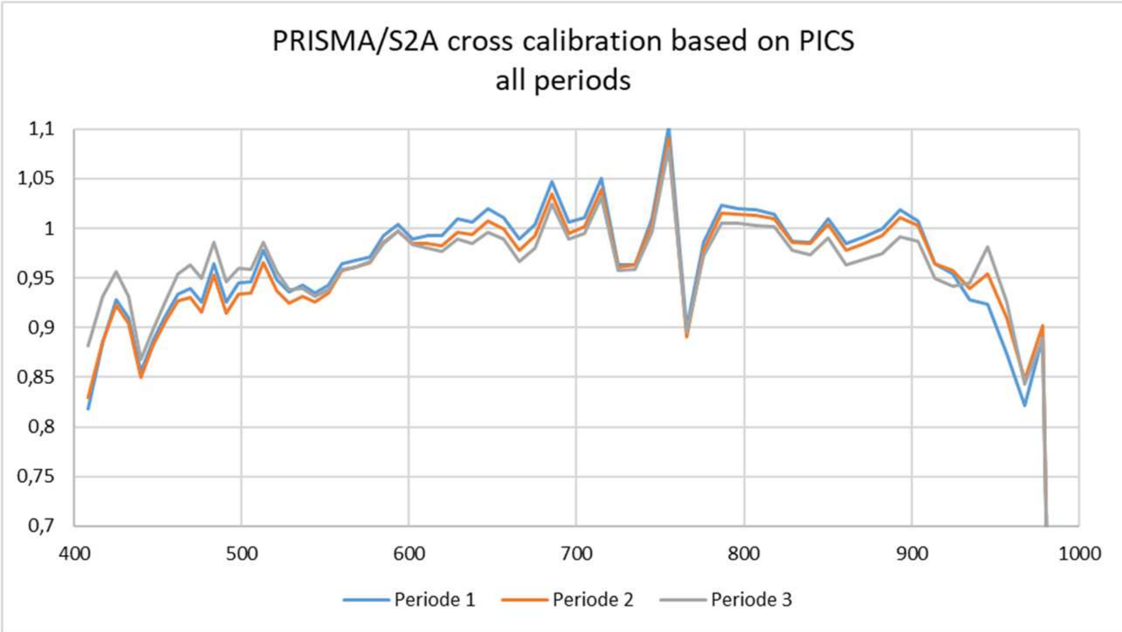
Reference sensors for cross-calibration: S2A & S3B

PRISMA CALIBRATION BASED ON PICS: RESULTS

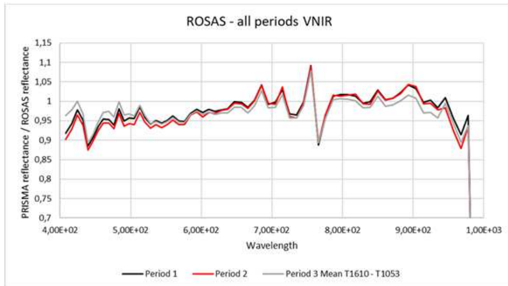


PRISMA CALIBRATION BASED ON PICS: VNIR RESULTS

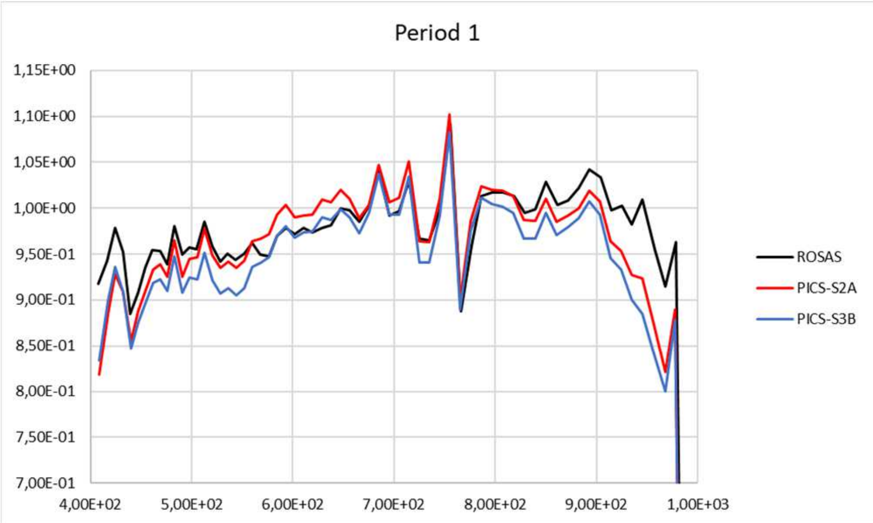
cnes

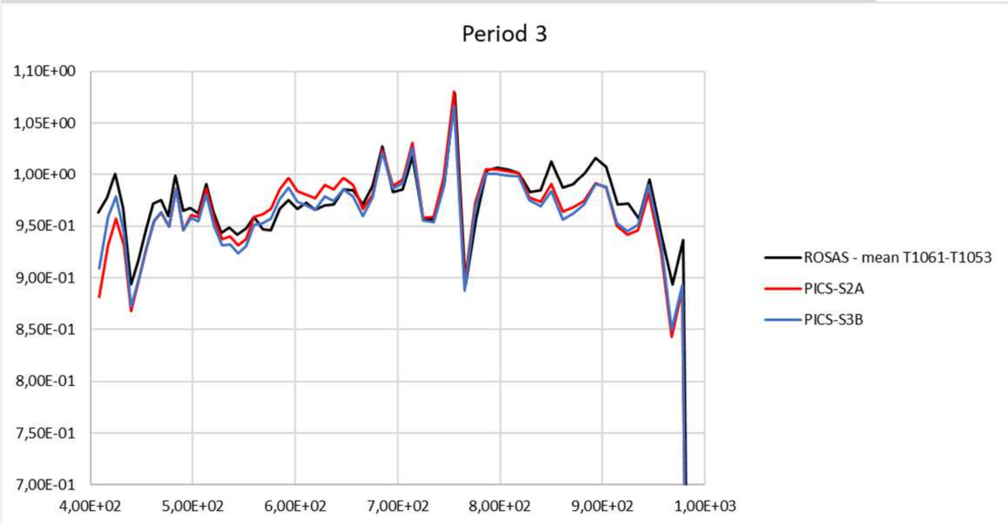


- **Good consistency between period 1 and 2, despite the weaker number of measurements for period 1 (recall: same consistency for ROSAS)**



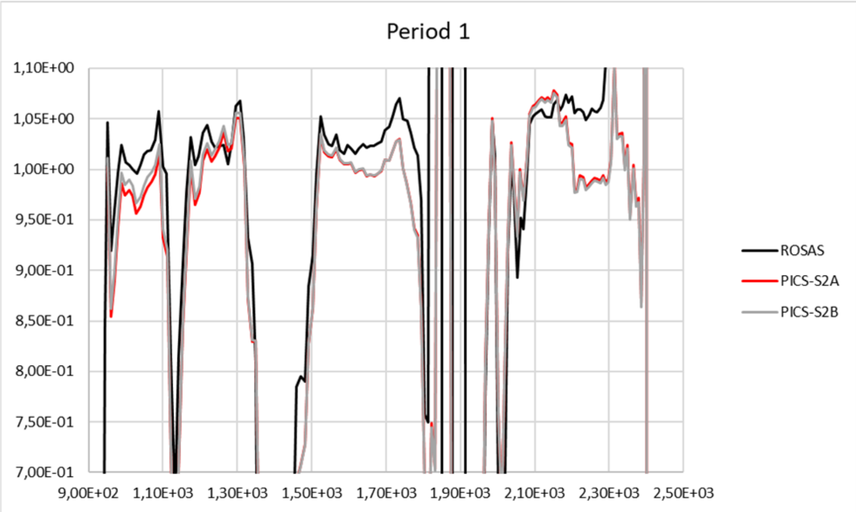
PRISMA CALIBRATION BASED ON PICS: VNIR RESULTS

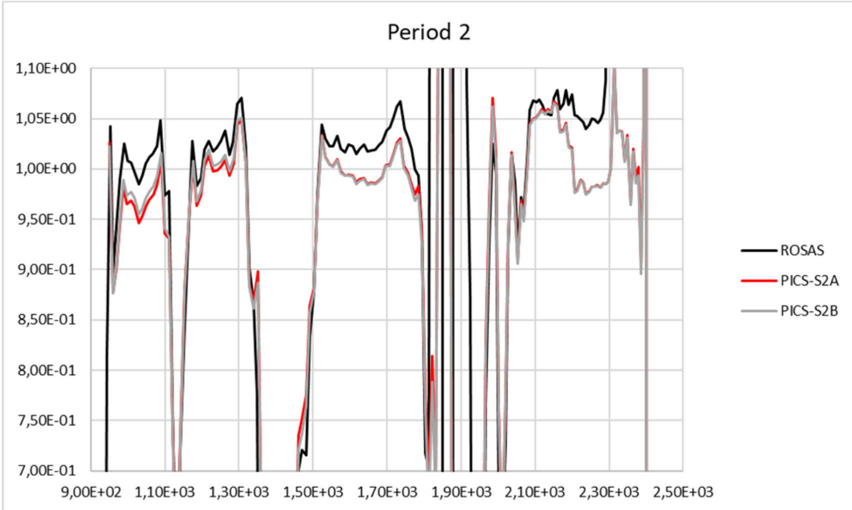


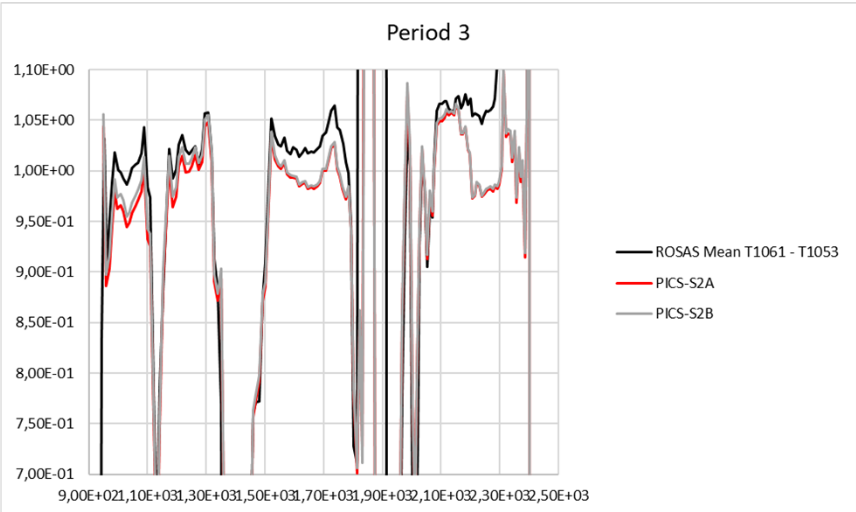


- **Good consistency between ROSAS (Gobabeb) and PICS results for period 2 and 3 (2-3% max variation around 0.9µm)**
- **Period 1: variability a bit more important between ROSAS, S2A and S3B probably due to the weaker number of measurements for PICS**

PRISMA CALIBRATION BASED ON PICS: SWIR RESULTS







- **3% variation between ROSAS and S2 PICS around 1.6µm**
- **6 % variation between ROSAS and S2 PICS around 2.2µm: ROSAS has no band around 2.2 µm wether Sentinel-2 has one**

⇒ We are more confident in S2A cross-calibration than for SWIR bands

PRISMA CALIBRATION: CONCLUSION

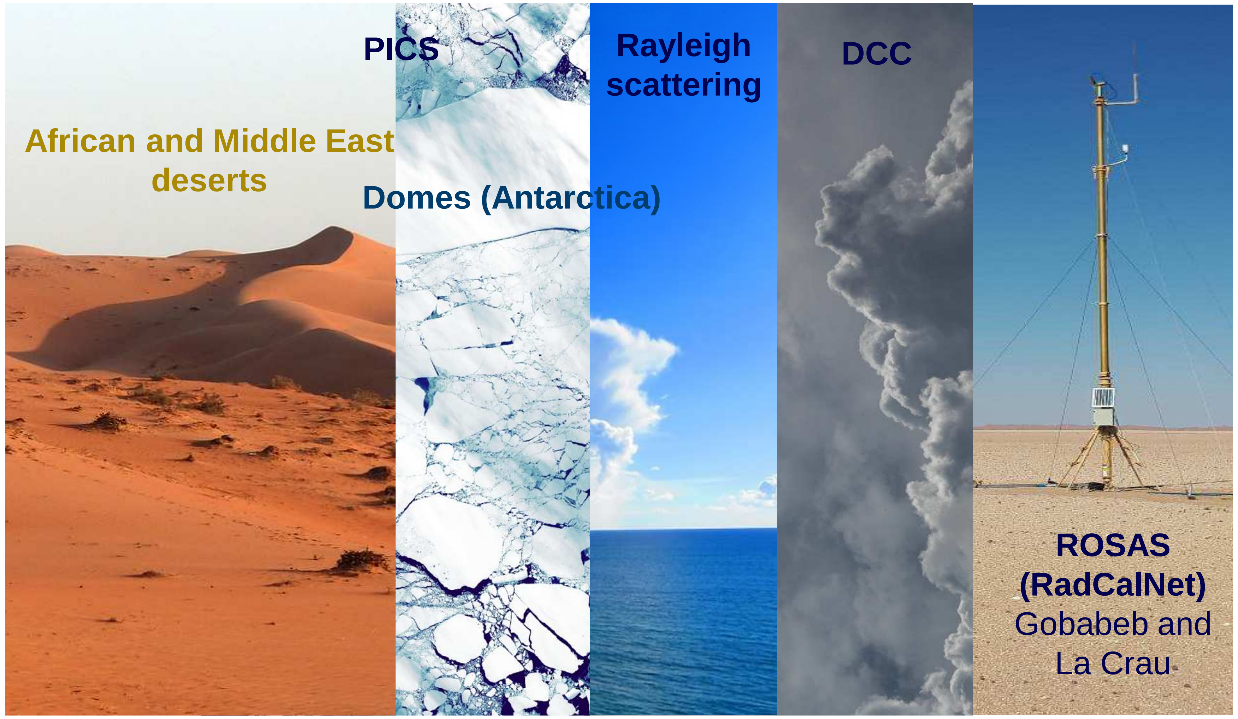
- Weak variation between the different period
- Strong variation, for short wavelengths, with regards to the official calibration
- PICS calibration was improved thanks to statistics (more data processed) and BOA PICS spectral reflectance interpolation based on reference spectra combining GOME-2 data and ONERA lab characterization

⇒ **Proposal to base PRISMA calibration on SENTINEL-2A cross-calibration results**
and to use ROSAS sites for validation for 2 reasons:

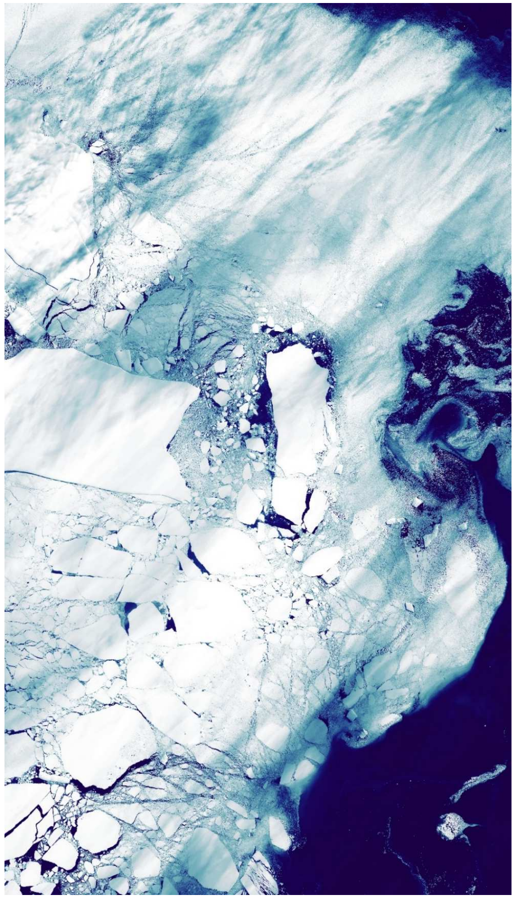
- consistency between PICS and ROSAS (except around 2.2µm)
- better to have PRISMA well cross-calibrated with to Sentinel-2 for users

SENTINEL-2 CALIBRATION

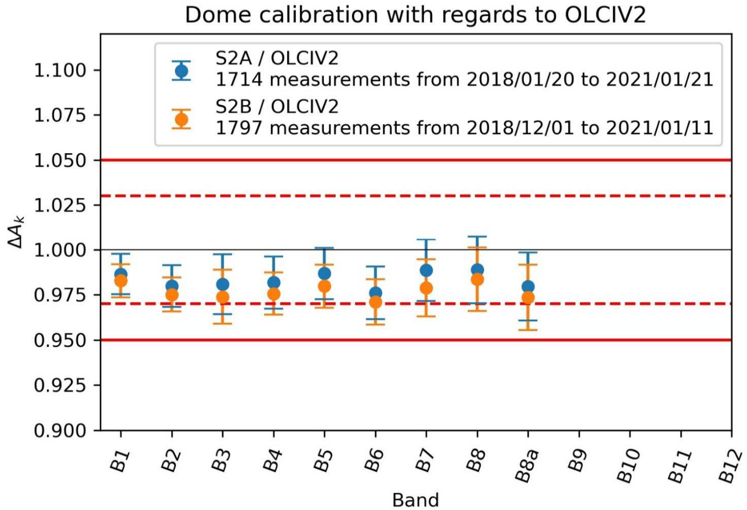
⇒ Methods used:

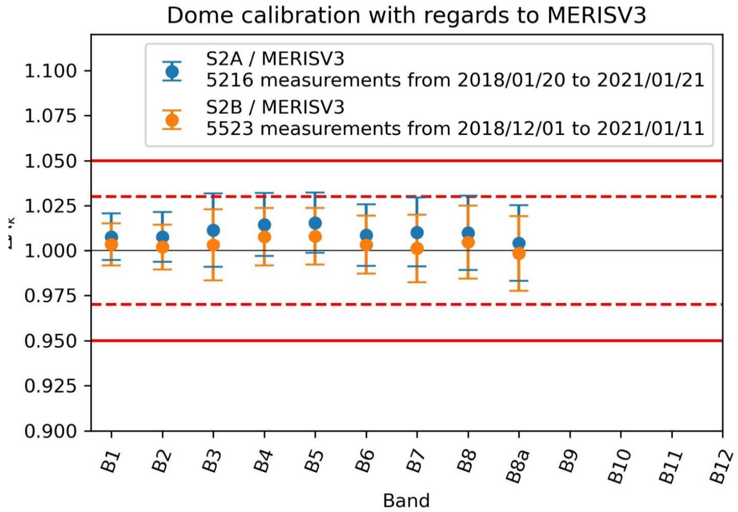


SENTINEL-2 CALIBRATION BASED ON ANTARCTICA SITES



Data collected before the radiometric bias correction between S2B and S2A

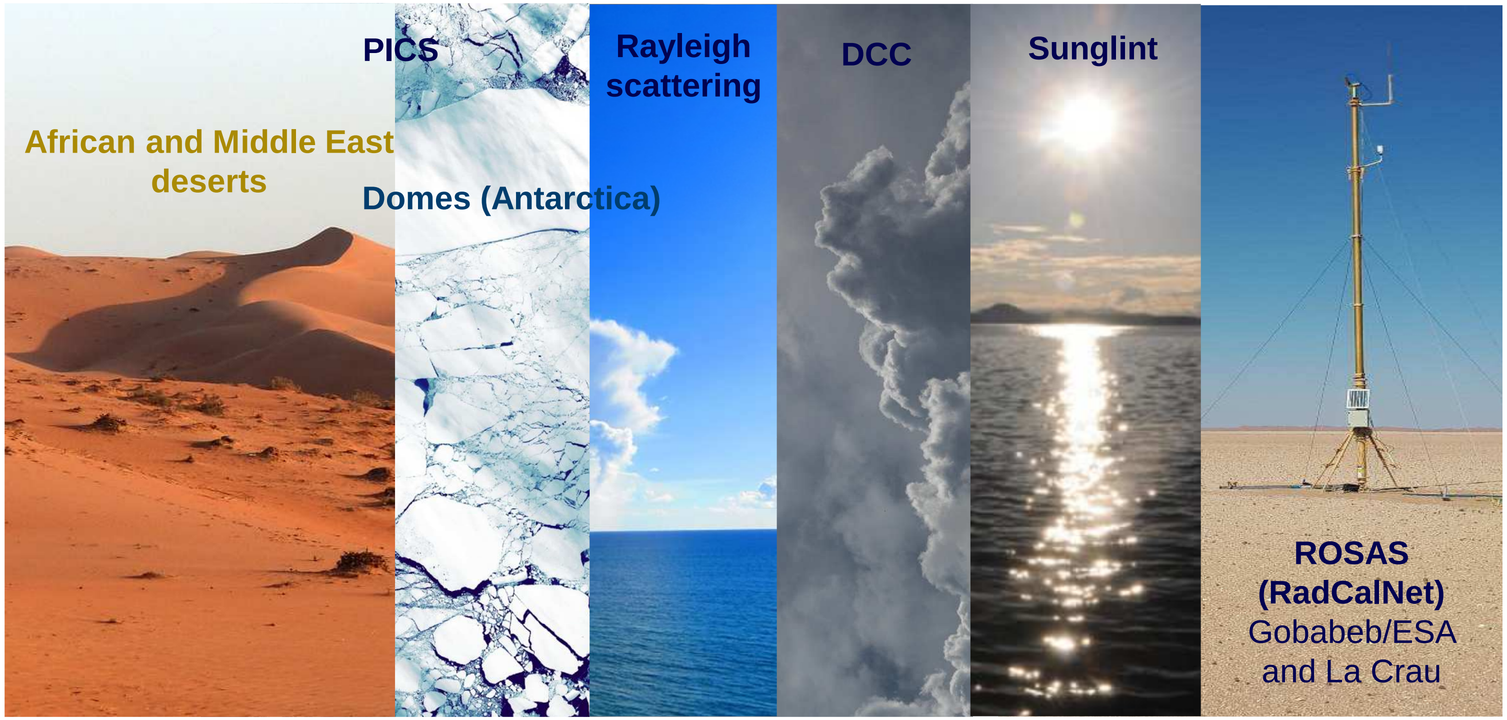




Dome sites are more suited for the short wavelengths whereas Desert sites can provide data up to SWIR bands.

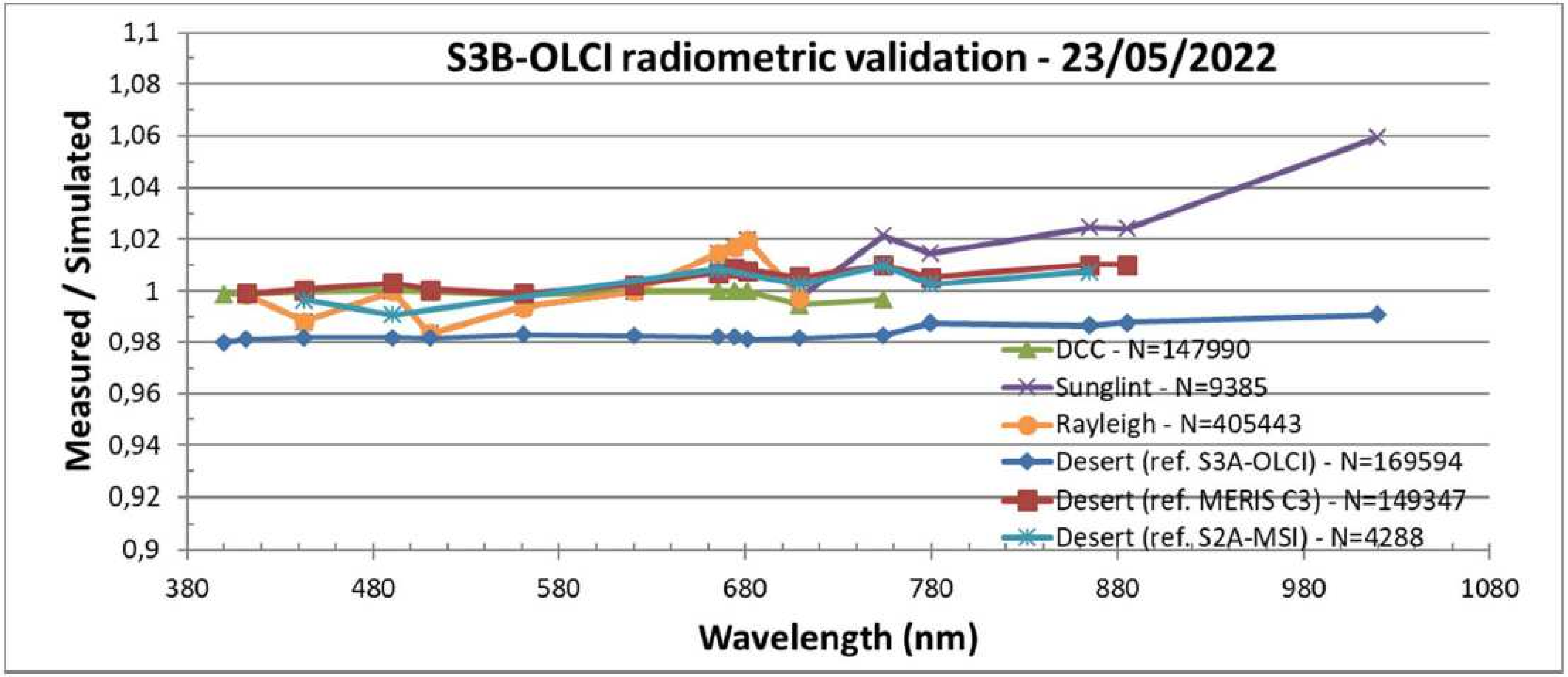
SENTINEL-3 CALIBRATION

⇒ Methods used:



SENTINEL-3 CALIBRATION SYNTHESIS

- PICS/Desert : Cross-calibration with ENVISAT-MERIS, S3A-OLCI ans S2A MSI as reference sensors
- DCC (deep convective clouds) and Sunglint: inter-band method (normalization Oa7-620)
- Rayleigh : absolute method



Context

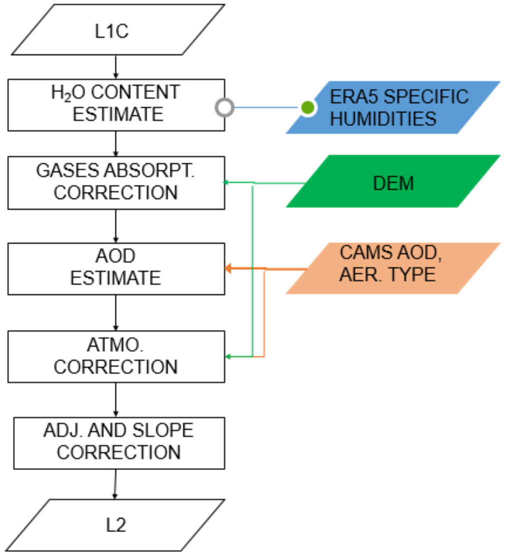
From 1986 to 2015, **SPOT 1 to 5 satellites** have acquired more than **30 million images** all over the world which represents a huge historical dataset. Images were acquired in multispectral – green, red, near-infrared and mid-infrared – and panchromatic bands, at spatial resolutions varying from 2,5 and 20 meters.

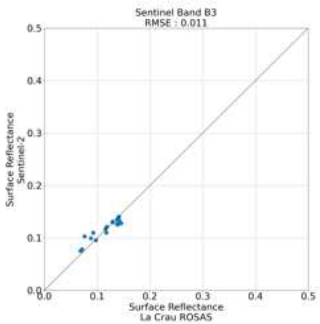
SPOT World Heritage project aims at gathering, processing at current standard levels and making freely available these SPOT images.

Currently, 19 million images are available at L1A processing level – radiometric corrections but no geometric correction - at https://regards.cnes.fr/user/swh/modules/60 portal. An on-demand SPOT L1C processing service is about to open. It performs geometric corrections and produces orthorectified images with Top of Atmosphere reflectances.

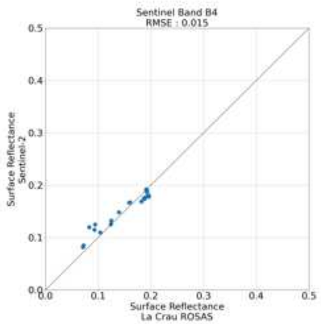
A **L2 level atmospheric corrections** designed for SPOT is being developed. These corrections will also become a user on-demand processing.

SPOT WORD HERITAGE ATMOSPHERIC CORRECTION





B3 : Green



B4 : Red

SENTINEL-2 tile T31TFJ in South East France
From 2018/04/01 to 2018/01/10

Level-1C image

Level-2 image
atmospheric corrections applied

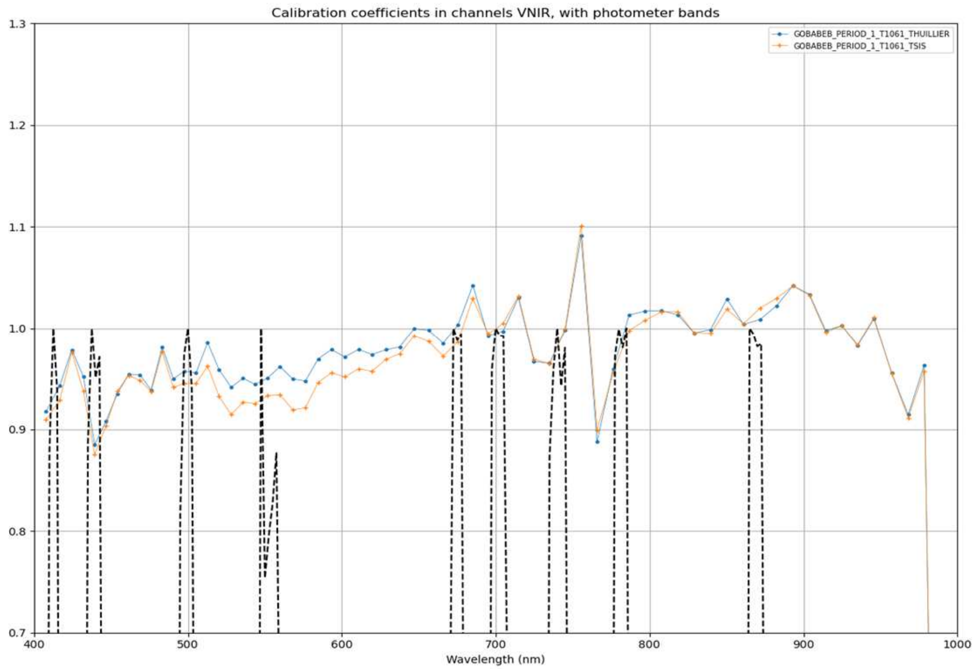
Salon de Provence, South East France, 2011/04/19
Colors : near-infrared, red, green

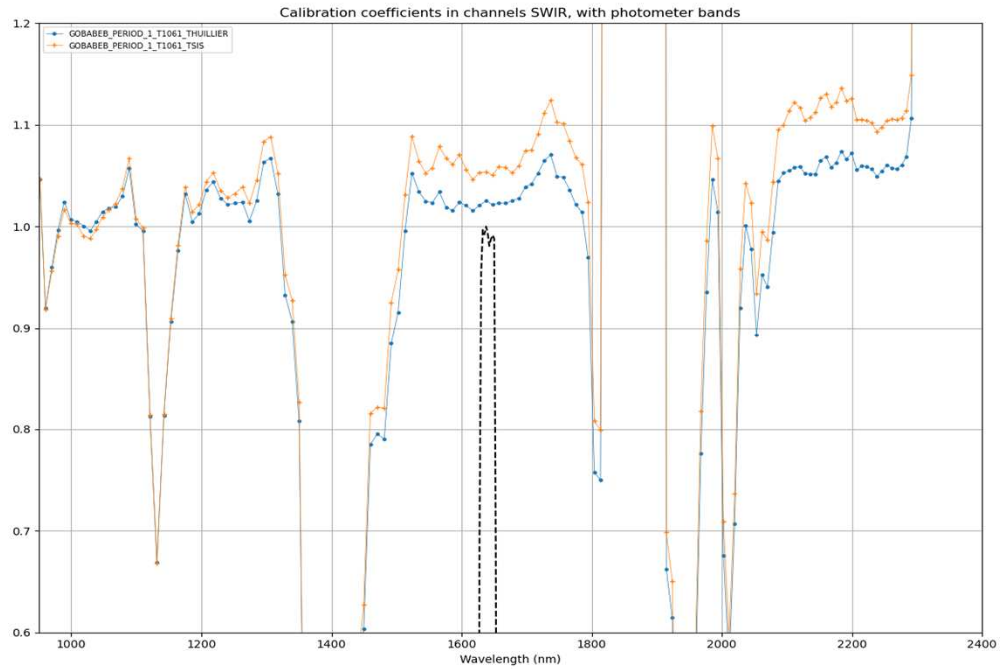
⇒ Validation on going based on La Crau measurements: example with Sentinel-2

Thank you!

Back up slides

PRISMA CALIBRATION BASED ON ROSAS: IMPACT OF THE SOLAR SPECTRUM





- **THUILLIER 2002 / TSIS: ⇒ 2-3 % variation around 550nm and 3% variation for SWIR bands**