HOW TO MAKE RADIOMETRIC VICARIOUS CALIBRATION METHODS READY FOR THE UPCOMING SPACE PROJECTS?

34TH CALCON TECHNICAL MEETING

Test Planning & Preparation session

2025-06-11

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OUTLINE

01

CNES IMAGE QUALITY TEAM

OUR ROLE WITHIN AN OPTICAL SPACE MISSION

During the mission development, the team is in charge of the **mission engineering**, ensuring the coherence between:

The end-users needs

The mission specifications

The image processing

Write specifications
Develop new algorithms
Analyse ground characterisation data
Balance instrument constraints and data processing
…

In-flight, the team is in charge of the **performance monitoring** (calibration and validation, ie. CAL/VAL):

- check that the mission specifications are met;
- tune the image processing to meet end-users requirements (calibration, artefact corrections, etc.);
- report to end-users the image quality status;
- optimise the overall system performances (go beyond specification if possible).

IN-FLIGHT PERFORMANCE MONITORING

The launch vibrations, the space environment as well as the instrument ageing **affect the instrument performances measured on-ground** and ask for an in-flight calibration.

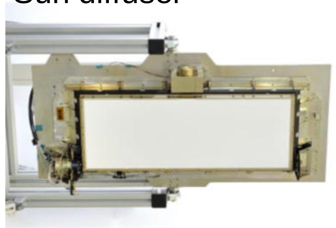
Main image quality performances which are evaluated on radiometry:

- inter-band calibration;
- spectral calibration;
- equalisation;
- temporal stability;
- signal to noise ratio;
- cross-talk and stray light artefacts;
- modulation transfer function;
- sensitivity to polarisation;
- **absolute calibration**.

Available tools for performance monitoring:

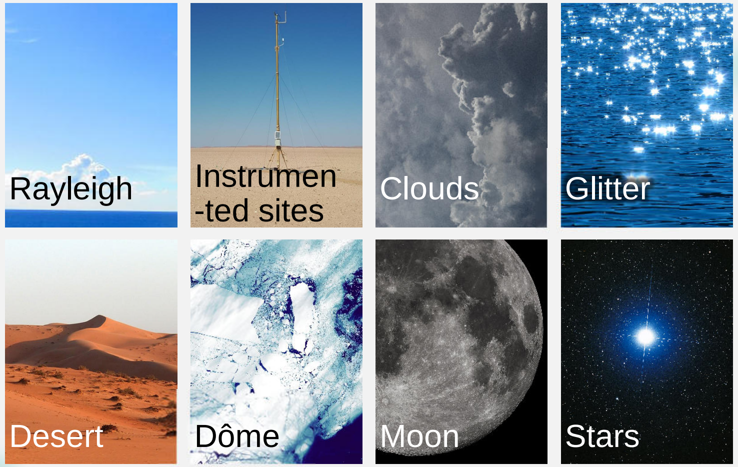
- on-board equipment (Sun diffusers, black body, calibration lamp, etc.) specific to the mission;
- and/or specific natural scenes which are analysed with **vicarious methods**, applicable to any missions.

Sentinel-2 on-board Sun diffuser



Salon-de-Provence test site (MTF estimation)

Vicarious calibration targets



Sener Aerospacial. SENTINEL-2. MSI Instrument Calibration & Shutter mechanism (CSM). **[Photograph]. In**: aerospatial.sener. Available on : <https://www.aeroespacial.sener/en/products/sentinel-2-msi-instrument-calibration-shutter-mechanism->.
CNES/Airbus. Salon-de-Provence test site for MTF estimation, France, taken by Pléiades. **[Photograph]**. 2018-07-18.

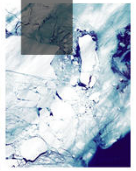
Fransoo. Désert dunes dune Oman paysage. **[Photograph]. In**: *Pixabay*. Disponible sur : <https://cdn.pixabay.com/photo/2019/02/09/15/52/desert-3985416_960_720.jpg>.
European Space Agency – Copernicus Sentinel-2 B. Antarctica coast - 2020-02-19 **[Photograph].** (S2B_MSIL1C_20200218T232349_N0209_R101_T54DXM_20200219T000933).
Maigler. Clouds Ocean Sky. **[Photograph]. In** : *Pixabay*. Disponible sur : <https://pixabay.com/photos/clouds-ocean-sky-horizon-scenic-91440/>.
CNES. Instrumented site in Namibia. **[Photograph].**
Potsclam Barro. Heavy clouds. **[Photograph]. In** : *Pexels*. Disponible sur : <https://www.pexels.com/photo/heavy-clouds-1828305/>.
Revera, Gregory H. Full Moon photograph taken 10-22-2010 from Madison, Alabama, USA. **[Photograph]. In**: *Wikipedia*. Disponible sur : <https://en.wikipedia.org/wiki/File:FullMoon2010.jpg>.
Akira Fujii. Ground-based image of Sirius. (2005) **[Photograph]. In**: *EsaHubble*. Disponible sur : <https://esahubble.org/media/archives/images/original/heic0516f.tif>.
Bokeh lights photograph of body of water. **[Photograph]. In**: *PickPik*. Disponible sur : <https://i1.pickpik.com/photos/776/729/281/sparkles-water-surface-water-aqua-53f125eb062438a9d49333d5eedd20a2.jpg>.

VICARIOUS CAL/VAL METHODS

The vicarious CAL/VAL methods are always based on the same concept:

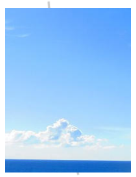
1 Acquire standard scenes $\rho_{\text{measurement}}$:

2 Simulate the expected signal $\rho_{\text{simulation}}$ based on:

- mean reflectance over predefined areas called PICS (Pseudo-Invariant Calibration Sites); ⟷ other measurements made by a reference sensor in the same geometrical conditions (plus exogenous data about the atmosphere);


- integrated signal from extra-terrestrial targets; ⟷ irradiance models built on previous astronomic studies;


- mean reflectance over natural phenomena (glitter, Rayleigh scattering, clouds reflectance); ⟷ physical models describing the phenomena (plus exogenous data about the atmosphere and the ocean);

- reflectance over instrumented sites; ⟷ simultaneous in-situ measurement.

3 Compute $\Delta A = \dfrac{\rho_{\text{measurement}}}{\rho_{\text{simulation}}}$

Fransoo. Désert dunes dune Oman paysage. **[Photograph]. In**: *Pixabay*. Disponible sur : <https://cdn.pixabay.com/photo/2019/02/09/15/52/desert-3985416_960_720.jpg>.
European Space Agency – Copernicus Sentinel-2 B. Antarctica coast - 2020-02-19 **[Photograph].** (S2B_MSIL1C_20200218T232349_N0209_R101_T54DXM_20200219T000933).
Maigler. Clouds Ocean Sky. **[Photograph]. In** : *Pixabay*. Disponible sur : <https://pixabay.com/photos/clouds-ocean-sky-horizon-scenic-91440/>.
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Bokeh lights photograph of body of water. **[Photograph]. In**: *PickPik*. Disponible sur : <https://i1.pickpik.com/photos/776/729/281/sparkles-water-surface-water-aqua-53f125eb062438a9d49333d5eedd20a2.jpg>.

02
UPCOMING MISSIONS AND CHALLENGES

TRISHNA, TAKING EARTH'S TEMPERATURE

A French-Indian mission to be launched in 2026:

- a VNIR-SWIR imager and the platform built in India;
- a thermal infra-red imager built in France.

Surface temperature measurement over land surfaces and coastal ocean at least every 3 days

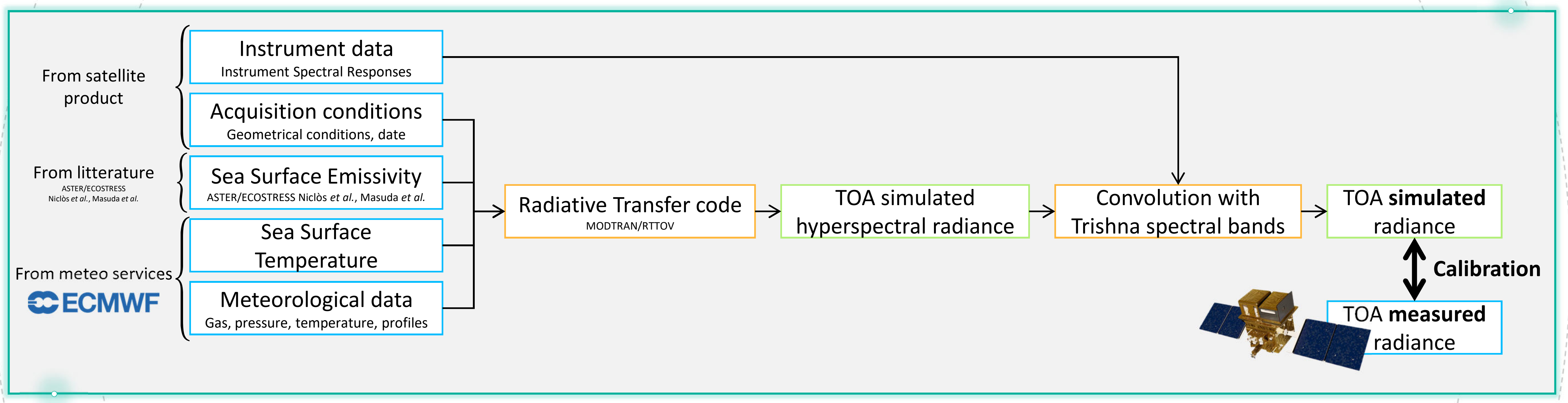
57 m nadir ground sampling distance and 4 spectral bands between 8 and 12 µm for the thermal infrared camera

Applications: plant water stress and evapotranspiration estimation for a better water management.

CAL/VAL challenge: extend our VNIR-SWIR methods up to the **thermal domain**.

TRISHNA, TAKING EARTH'S TEMPERATURE

CAL/VAL solution: comparison of the satellite measurement with radiances simulated over the ocean using ECMWF data.



Applied to 12,476 IASI measurements *(courtesy V. Capelle, LMD)* convoluted with Trishna spectral bands, the consistency between the real measurements and the simulations is **better than 0.4 K** (specification: 0.5 K).

Trishna spectral band	TIR1 (8.65µm)	TIR2 (9.0 µm)	TIR3 (10.6µm)	TIR4 (11.6 µm)
$\Delta \mathbf{BT}\ (\mathbf{K}) = \mathrm{BT(measurement)} - \mathrm{BT(simulation)}$	-0.37 ± 0.35	-0.38 ± 0.39	-0.20± 0.40	-0.30 ± 0.46

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TRISHNA

ECMWF. Logo of the European Centre for Medium-Range Weather Forecasts. [Logo]. In: *Wikipedia*. Available on: <https://upload.wikimedia.org/wikipedia/fr/4/42/Ecmw-Logo.png>. 23/08/2019.
© CNES/ill./REGY Michel. Illustration du satellite Trishna. [Illustration]. In: *Photothèque CNES*. Ref. P67256. 28/05/2021.
Indian Space Research Organisation. Logo of Indian Space Research Organisation. [Logo]. In: *Wikipedia*. Available on: <https://en.m.wikipedia.org/wiki/File:Indian_Space_Research_Organisation_Logo.svg>. 21/04/2011.

TRISHNA, TAKING EARTH'S TEMPERATURE

Committee on Earth Observation Satellites

CAL/VAL solution: a network of in situ measurement is set up with thermal infrared instruments.

After the success of the RadCalNet network dedicated to VNIR-SWIR sensor cal/val, the CEOS is pushing an equivalent network called **TIRCalNet** for the **thermal infra-red** (TIR) sensors to:

- collect surface temperature, emissivity, and atmospheric data necessary for the simulation of TIR observations;
  - Level-1 calibration: comparison with observation simulated on Top Of Atmosphere;
  - Level-2 validation: direct comparison with observations;
- increase the number of matchups between in-situ measurements and space sensor observations with autonomous instruments;
- verify the radiometric consistency between space sensors.

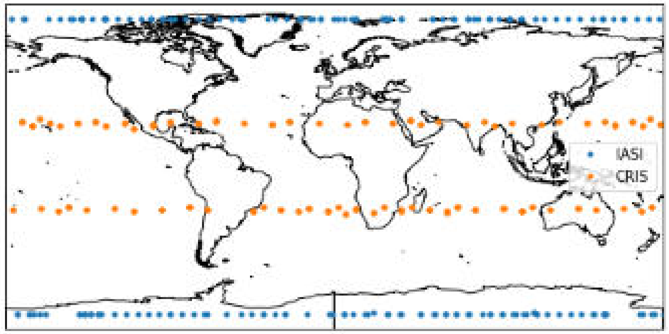
CNES participates to this effort by:

- coordinating with ESA the TIRCalNet working group;
- **deploying autonomous instrumentations**:
  - JPL radiometer (1 large band, high accuracy);
  - CIMEL CE312 (5+1 ASTER-like bands);
  - 4 KT15.99 (Trishna-like bands).
- developing a **processing chain**;
- building an **uncertainty budget** on the Top Of Atmosphere signal simulation based on in-situ measurements.

CEOS. CEOS Logo - Black Text Right. [Logo]. In: *ceos.org*. Available on: <https://ceos.org/document_management/Communications/CEOS-Logos/CEOS_logo_colour_black_text_right.png>.
Dick, Arthur. Photos montage mât sectionnel La Crau. [Photograph]. Ref. 20250325_164528.

TRISHNA, TAKING EARTH'S TEMPERATURE

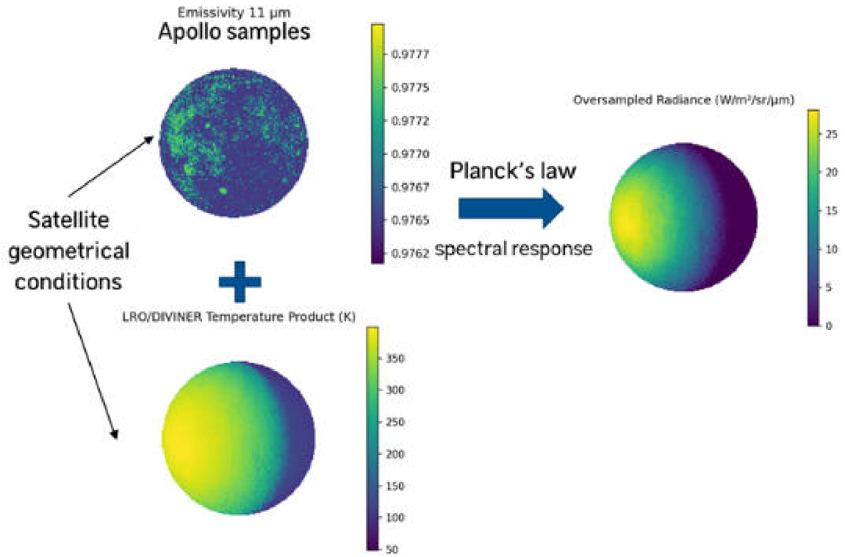
CAL/VAL solution: other more prospective approaches are under investigation to complement the previous ones.



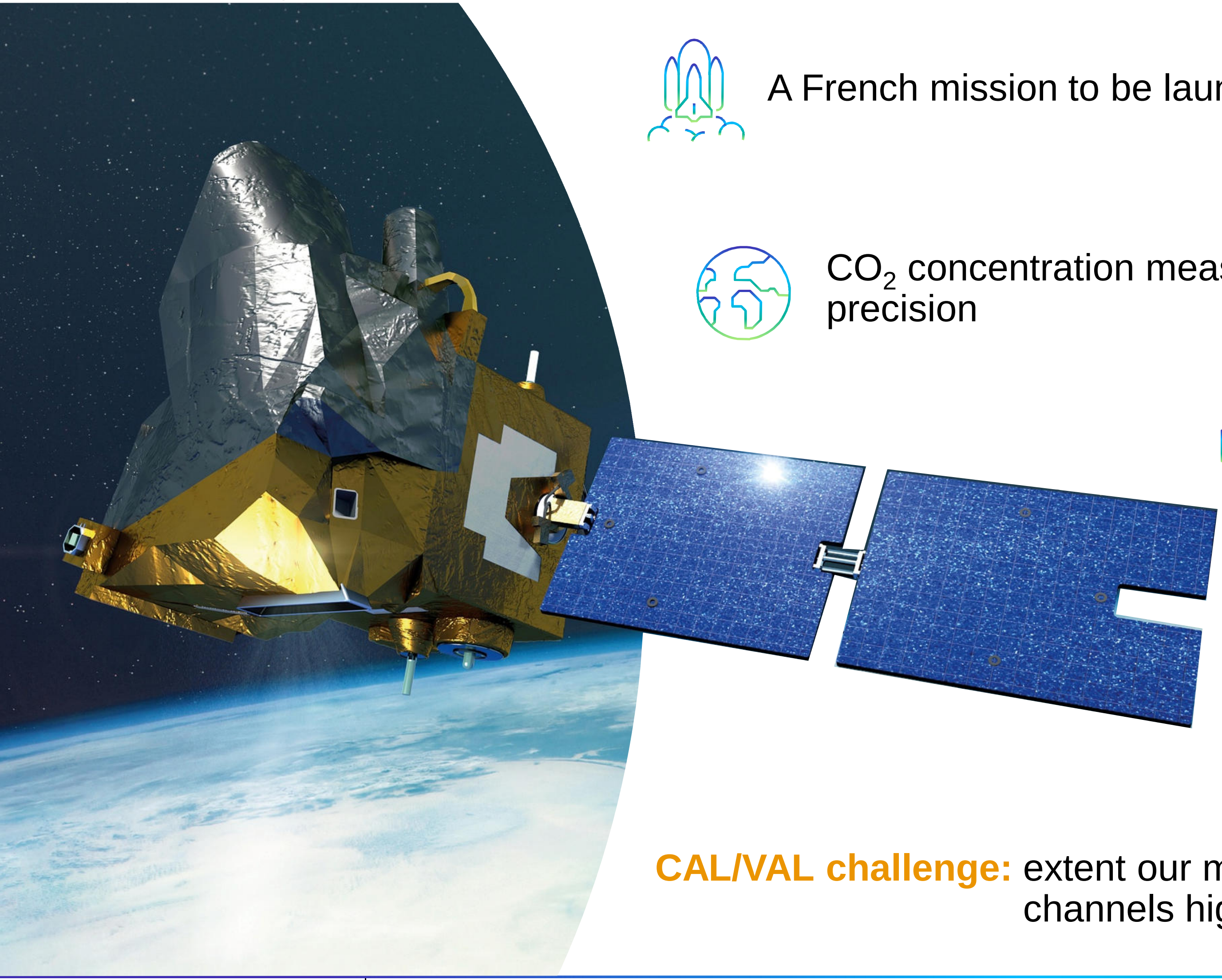
Trishna match-ups with CRIS (13:30) and IASI (9:30)

The intercalibration with other **reference sensors** (such as IASI, CrIS, SBG, LSTM, etc.) over homogeneous areas can be applied for quasi-simultaneous nadir observations.

The adaptation of the lunar irradiance model is under study to perform **calibration over the Moon**.



MICROCARB, MEASURING GLOBAL CO_2 DISTRIBUTION



A French mission to be launched soon (summer 2025)

CO_2 concentration measurement on Earth every 25 days with a 1 ppm precision

4.5 x 9 km spatial resolution with 4 spectral domains [0.76 - 2.04] sampled at 0.08 nm

Applications: better understand the carbon cycle.

CAL/VAL challenge: extent our methods to the very **high spectral resolution** with spectral channels highly **affected by atmospheric absorption**.

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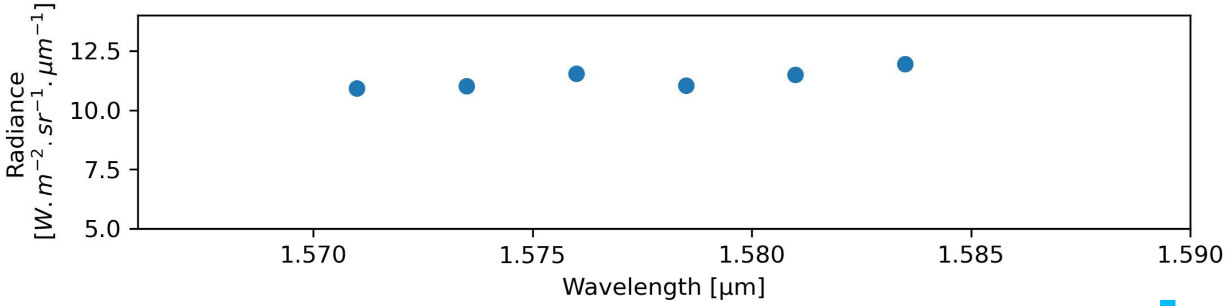
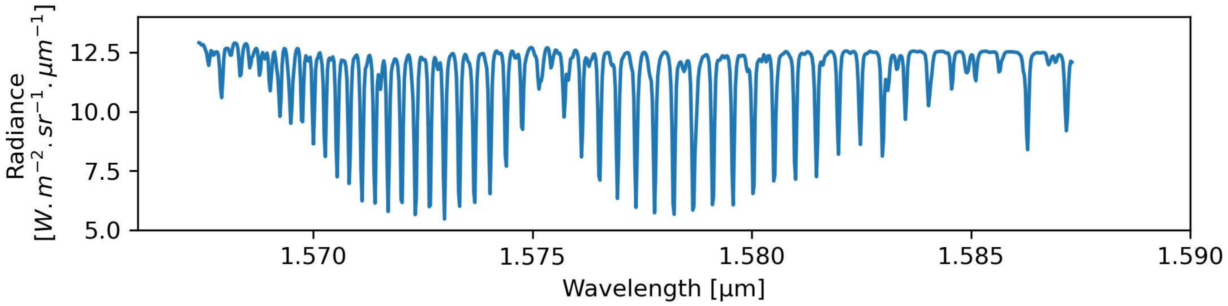
MICROCARB, MEASURING GLOBAL CO_2 DISTRIBUTION

CAL/VAL solution: the radiative transfer models of the vicarious calibration methods are updated with high-resolution ones (asking for computation time optimisations).



Operationally, our calibration processes are mainly based on a model learnt on 6S simulations with a **2.5 nm spectral resolution**.

E. F. Vermote, D. Tanre, J. L. Deuze, M. Herman, et J.- Morcette, « Second Simulation of the Satellite Signal in the Solar Spectrum, 6S: an overview », *IEEE Transactions on Geoscience and Remote Sensing*, vol. 35, nº 3, p. 675-686, 1997.

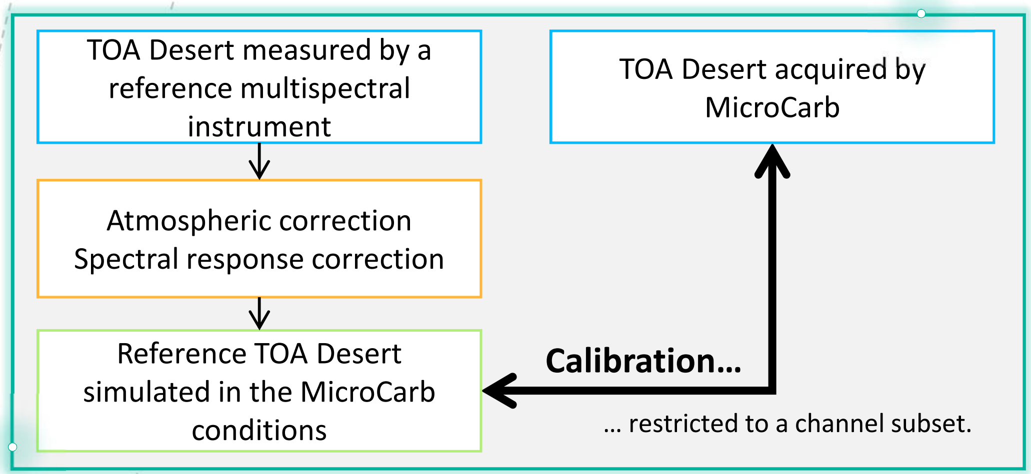


For MicroCarb, the calibration process will include 4A/OP computations with high **spectral resolution 0.0006-0.004 nm** (0.01 cm^{-1})

N. A. Scott et A. Chedin, « A Fast Line-by-Line Method for Atmospheric Absorption Computations: The Automatized Atmospheric Absorption Atlas », *Journal of Applied Meteorology and Climatology*, vol. 20, nº 7, p. 802-812, 1981, doi: 10.1175/1520-0450(1981)020<0802:AFLBLM>2.0.CO;2.

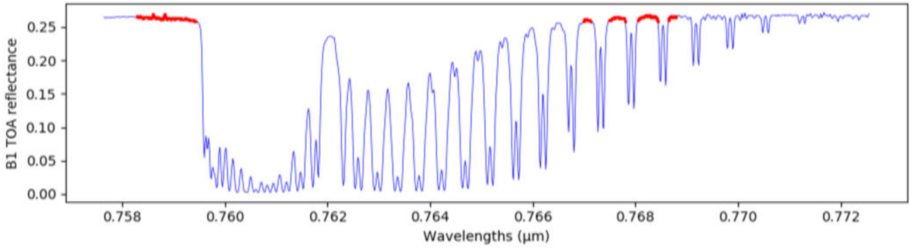
MICROCARB, MEASURING GLOBAL CO_2 DISTRIBUTION

CAL/VAL solution: the Desert method is applied by building an equivalent multi-spectral sensor based on a subset of spectral channels, non-affected by atmospheric absorption. The approach is also applicable to the Glitter method.



Since the need is not to calibrate each spectral channel individually but to set the global absolute level, MicroCarb can **be turned into a multispectral** mission by aggregating the spectral channels non-affected by atmospheric absorption.

The approach was applied to compare OCO-2 (close to MicroCarb) with Sentinel-3 OLCI-B, only the red OCO-2 channels below are selected. The results are consistent from one Desert to another (better than 1 %).



Sites	Match-ups	ΔAk	σ
Libye 2	14,028	0.989	0.013
Libye 4	1221	0.983	0.012
Egypte 1	7918	0.989	0.016
Arabie 1	90	0.984	0.015

3MI, CHARACTERISING LIGHT POLARISATION

A European mission from EUMETSAT to be launched soon (summer 2025). CNES is a partner for the CAL/VAL expertise (gained from previous mission POLDER).

Multi-viewing, multi-spectral and polarisation measurements over the globe every day

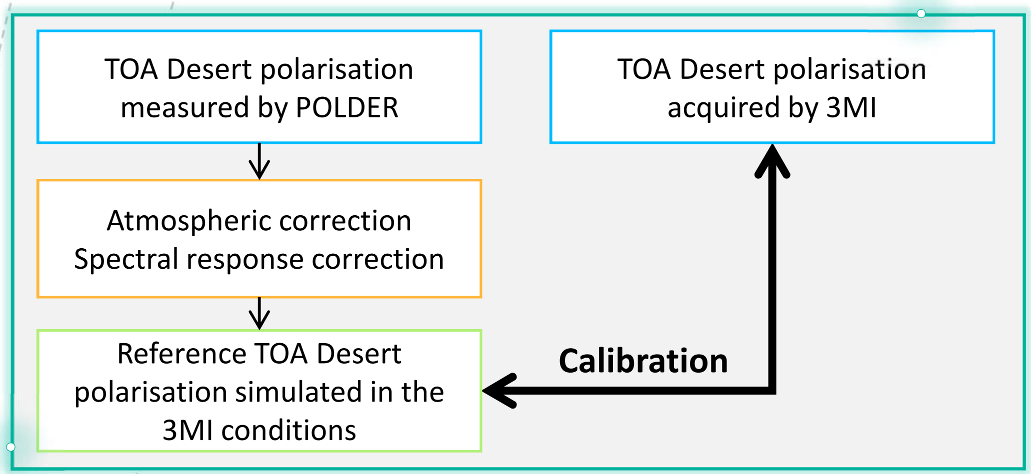
4 km nadir ground sampling distance, 12 spectral bands between 0.41 and 2.2 µm with 9 polarised bands (-60°, 0°, +60°) and 12 to 14 viewing directions.

Applications: characterisation of aerosol, cloud and surface albedo.

CAL/VAL challenge: include the **polarisation** into our methods.

3MI, CHARACTERISING LIGHT POLARISATION

CAL/VAL solution: the cross-comparison on Deserts (PICS) can be made with the POLDER mission as reference.



The Desert processing is adapted to take into account polarised measurements:

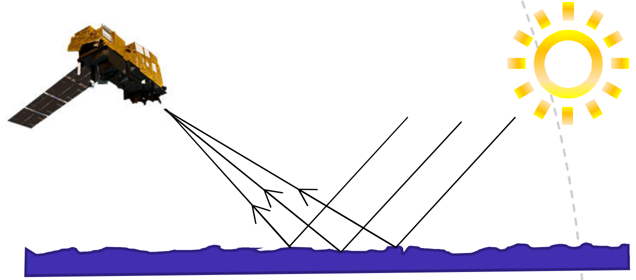
- validate that the **atmospheric correction** steps include the polarisation;
- apply a **Bidirectional Polarisation Distribution Function** to correct for the geometrical discrepancies between the reference measurements and the 3MI ones.

The approach has not been tested yet but will be applied during the 3MI commissioning phase.

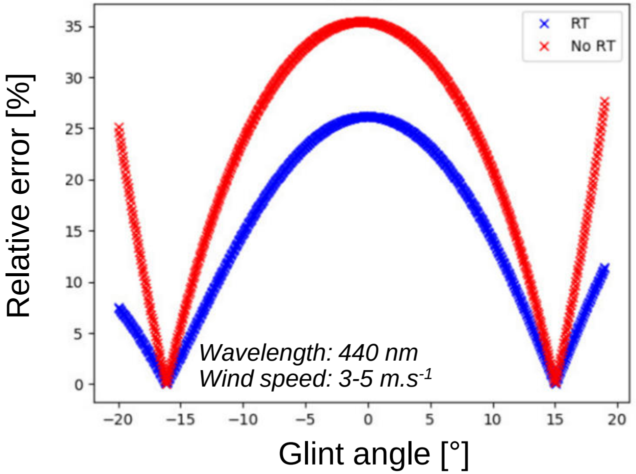
3MI, CHARACTERISING LIGHT POLARISATION

CAL/VAL solution: a glitter-based approach is under development, and the first tests on POLDER images are promising.

In Glitter conditions, the ocean surface roughness induces some specular reflexions of the Sun toward the sensor. The resulting polarised signal can be accurately simulated providing the surface wind speed is well-known.



Error on the Glitter signal due to a 2 $m.s^{-1}$ error on wind speed



The meteorological services provide surface wind speed with a typical 2 $m.s^{-1}$ uncertainty which induces up to 35 % of error on the simulated signal!

However, a recent study has emphasized specific angular conditions which **reduce the simulation sensitivity to the input wind speed to ~2 %**. The first application to POLDER data is promising.

M. S. Djellali, J. Riedi, S. Marcq, B. Fougnie, S. Hioki, et J.-M. Nicolas, « Development of calibration methods using specular reflection over the ocean for the Multiviewing, Multichannel, Multipolarization Imager (3MI) of the EUMETSAT Polar System – Second Generation (EPS-SG) », in *Image and Signal Processing for Remote Sensing XXV*, L. Bruzzone, F. Bovolo, et J. A. Benediktsson, Éd., Strasbourg, France: SPIE, oct. 2019, p. 3. doi: 10.1117/12.2532501.

PhD. thesis supported by CNES.

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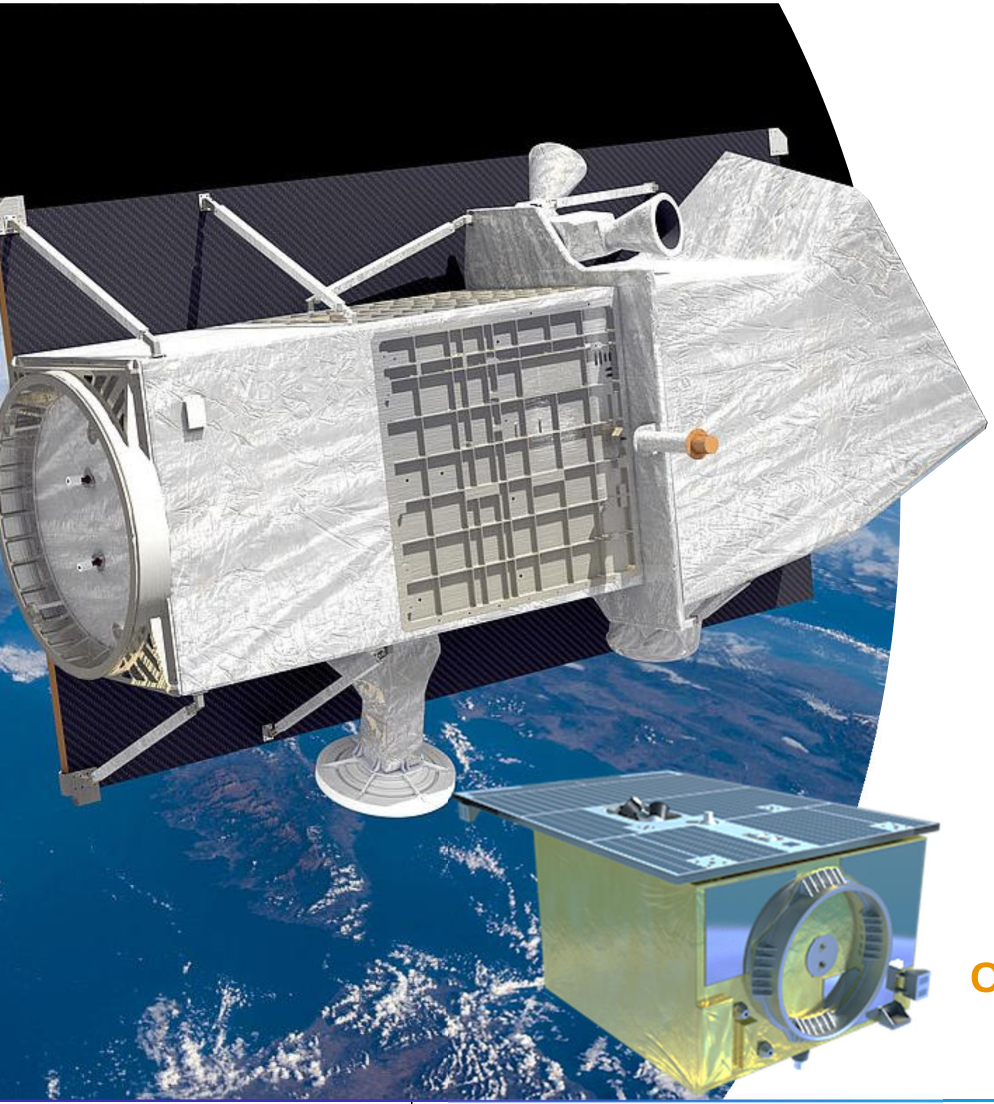
SPECTRO-IMAGERY, FUTURE OF MULTI-SPECTRAL IMAGERY



CNES has built partnership with the team in charge of the recent spectro-imager missions born in Europe:

- PRISMA from the Italian Space Agency (2019);
- ENMAP from the German Space Agency (2022).

On-demand acquisitions, repeat cycle every 27-29 days

30 m ground sampling distance and ~200 continuous spectral channels (around 10 nm FWHM and 10 nm spectral step) between 0.4 and 2.5 µm

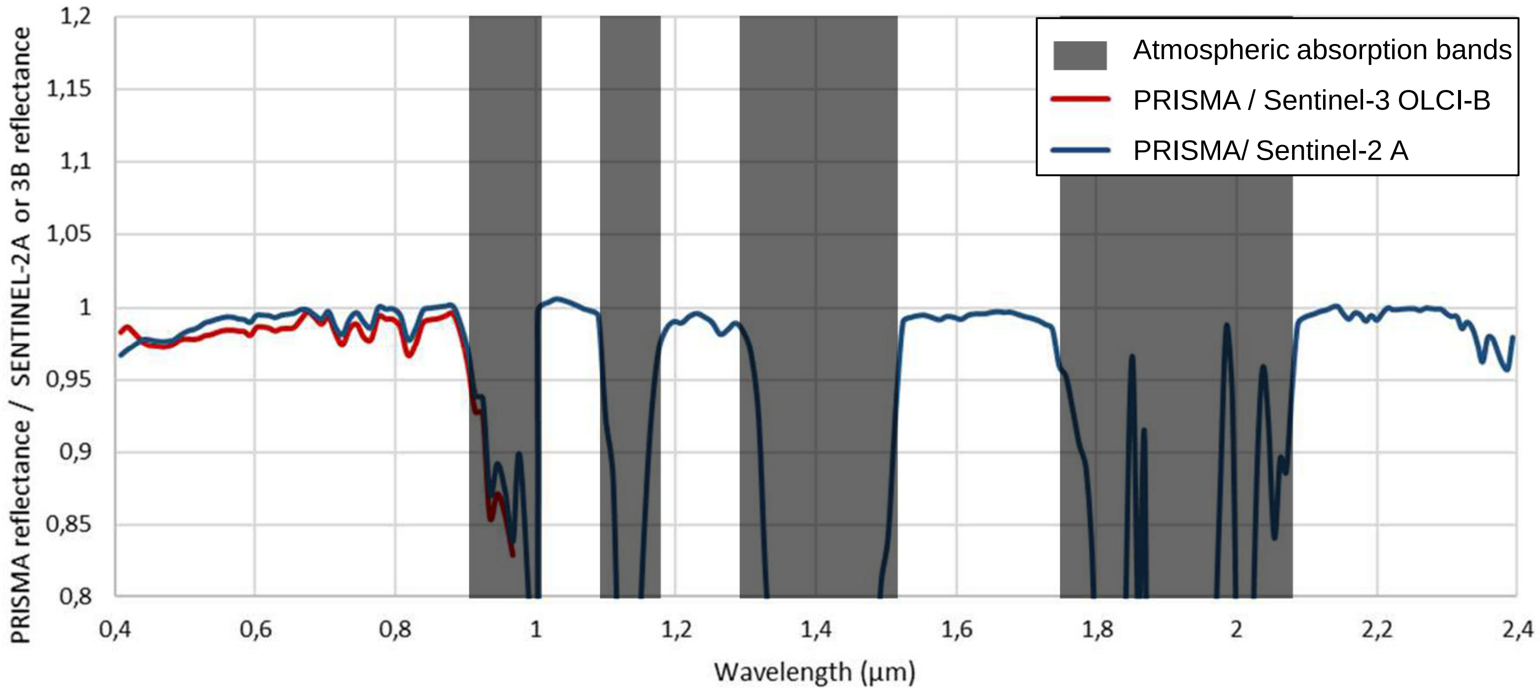
Applications: mineralogy, vegetation, etc.

CAL/VAL challenge: extent our methods to **continuous spectrum**.

SPECTRO-IMAGERY, FUTURE OF MULTI-SPECTRAL IMAGERY

CAL/VAL solution: on PRISMA, the PICS method and in situ measurements were adapted with good results.

PRISMA / Sentinel-2A & 3B Cross-calibration based on PICS (August 2022 – April 2023)



To obtain these results, the following improvements were implemented:

- switch **radiative transfer** to the 6SV native resolution (2.5 nm);
- interpolate the multi-spectral data with a **prior knowledge of the ground spectrum** (measured in-situ).

ASI has requested CNES to assess the absolute gains and the loss of sensitivity of PRISMA over PICS. The **official PRISMA calibration includes the CNES cross-calibration** with Sentinel-2A over PICS (and validated on Gobabeb in-situ measurements).

SPECTRO-IMAGERY, FUTURE OF MULTI-SPECTRAL IMAGERY

CAL/VAL solution: the instrumented sites initially dedicated to multi-spectral calibrations are going to be updated with a new hyperspectral instrument.

CNES and CIMEL (the company which has already developed the current multi-spectral instrument) are working together on a hyperspectral instrument. The solution embeds three spectro-radiometers:

	VNIR	SWIR 1	SWIR 2
Spectral range	300 – 1 100 nm	900 – 1 700 nm	1 300 – 2 600 nm
Spectral step	0.5 nm	1.5 nm	5 nm
FWHM	1.0 – 1.5 nm	5.5 – 6.0 nm	9.5 – 10.5 nm
Sensor	Si	InGaAs	cooled InGaAs (-20 °C)
Size [mm]	150 x 121.5 x 78.5	115 x 52.5 x 52.3	115 x 50 x 87

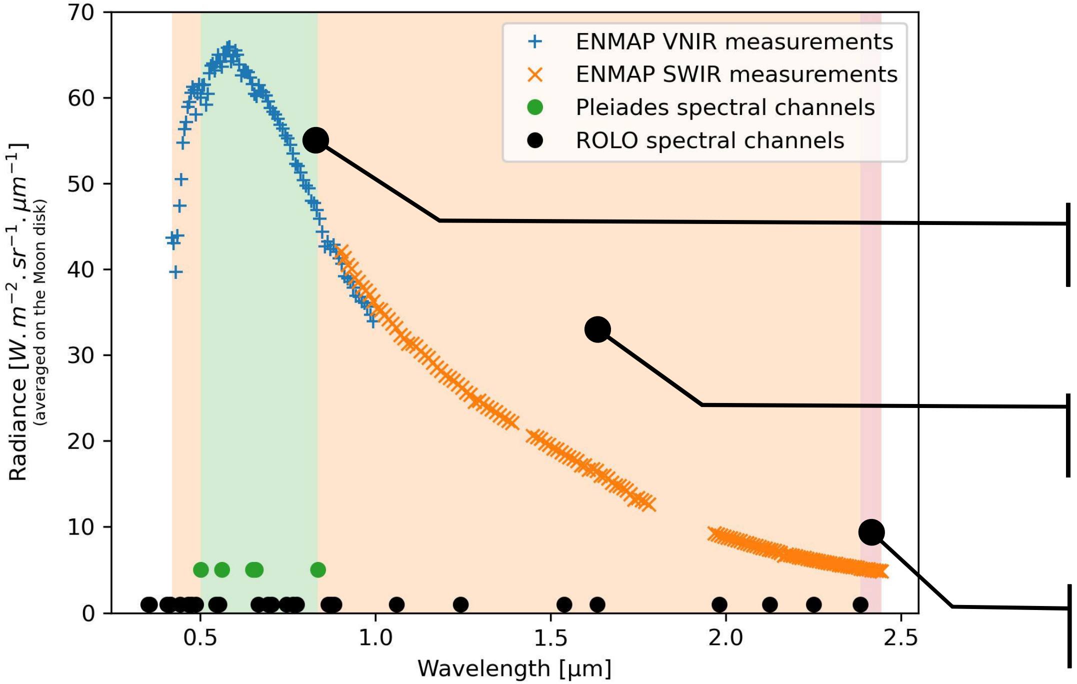
CNES brings its expertise on the **radiometric aspects** (operating point tuning), the **instrumental characterisation** (in particular the spectral responses characterisation) and the **processing chain**. The comparison phase between the hyperspectral and multispectral instruments is under preparation (expected to start end 2025) .

SPECTRO-IMAGERY, FUTURE OF MULTI-SPECTRAL IMAGERY

CAL/VAL solution: on ENMAP, to validate the atmospheric absorption bands calibration, a Moon-based approach is under investigation with first promising results.

Preliminary results

The ROLO-CNES model is a correction of the ROLO model based on ~1 400 Moon images taken by the Pleiades mission: the SWIR range is thus less reliable.



Spectral validity of the ROLO-CNES model

Reliable model with CNES correction

Model with **extrapolated CNES correction**

Extrapolated ROLO model

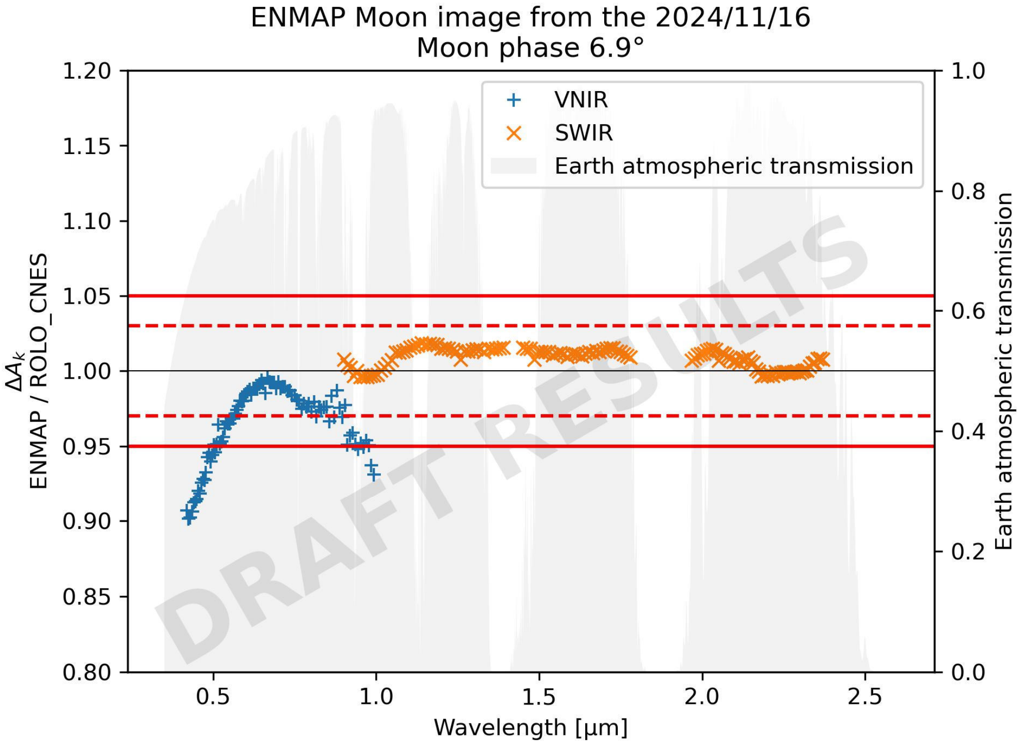
DLR. ENMAP Moon image with phase angle 6.9°. [Satellite image]. 2024-11-16.

SPECTRO-IMAGERY, FUTURE OF MULTI-SPECTRAL IMAGERY

CAL/VAL solution: on ENMAP, to validate the atmospheric absorption bands calibration, a Moon-based approach is under investigation with first promising results.

Preliminary results

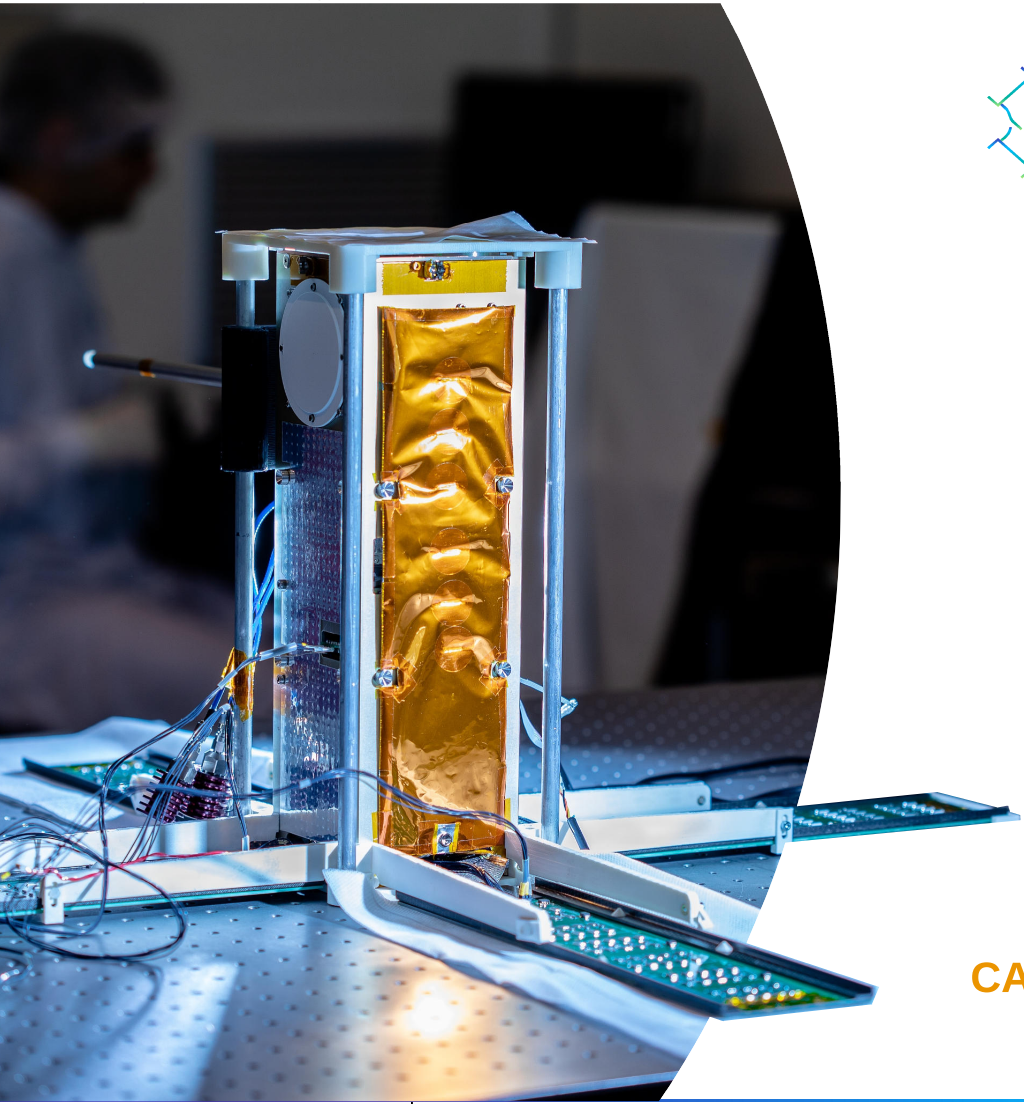
Preliminary results obtained on a single image with the ROLO-CNES model and the TSIS solar spectrum.



- By using the Moon, troubles introduced by the atmospheric absorption are avoided.
- **On-going work:** the behaviour in the blue bands are under investigation…

DLR. ENMAP Moon image with phase angle 6.9°. [Satellite image]. 2024-11-16.

"NEW-SPACE", ADDRESS MULTIPLE MISSIONS



The space ecosystem is growing fast with a large number of French start-ups which might need help on CAL/VAL aspects.

A lot of missions are dedicated to Earth observation.

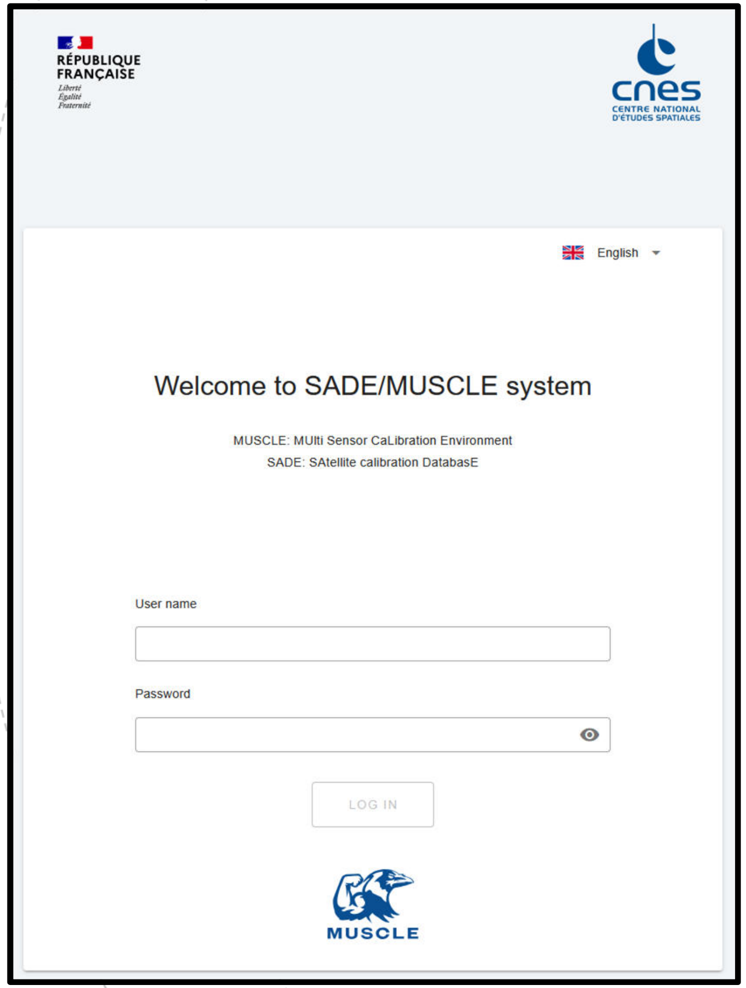
The instruments often acquire spectral bands between 0.4 and 1.7 µm.

Applications: diverse.

CAL/VAL challenge: offer a CAL/VAL support to a **growing number of partners**.

"NEW-SPACE", ADDRESS MULTIPLE MISSIONS

CAL/VAL solution: provide a remote access to our CAL/VAL tools.



Since 2002, CNES has gathered all the vicarious calibration methods into a **unified software** called Muscle and a **common database** called SADE in order to:

- ensure traceability;
- perform massive cross-comparison between sensors;
- reduce validation time and costs to integrate new sensors;
- propagate any methodology improvement to all available sensors.

To address the growing number of partners interested in vicarious calibration/validation methods, the newly developed version will **be accessible on the Web**. The partners will be able to perform their own calibration.

CONCLUSIONS

GET READY FOR A NEW MISSION

Preparing a new space mission is also a matter of **vicarious calibration** methods when it comes to **ensure reliable datasets comparable to past and present missions**.

New missions

Trishna, MicroCarb, 3MI, spectro-imagers, “New space” missions, …

New challenges

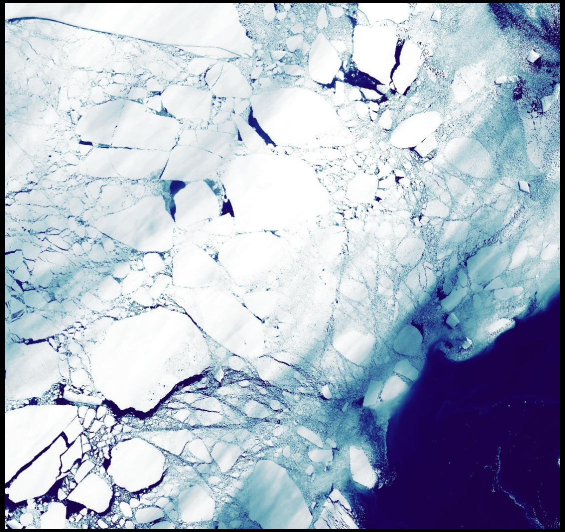
Thermal infra-red, high spectral resolution, polarisation, continuous spectrum, …

New solutions

Simulate Ocean signal based on meteorological data, integrate new radiative transfer code, extend the Moon model, open tools to partners, …








THANK YOU FOR YOUR ATTENTION

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