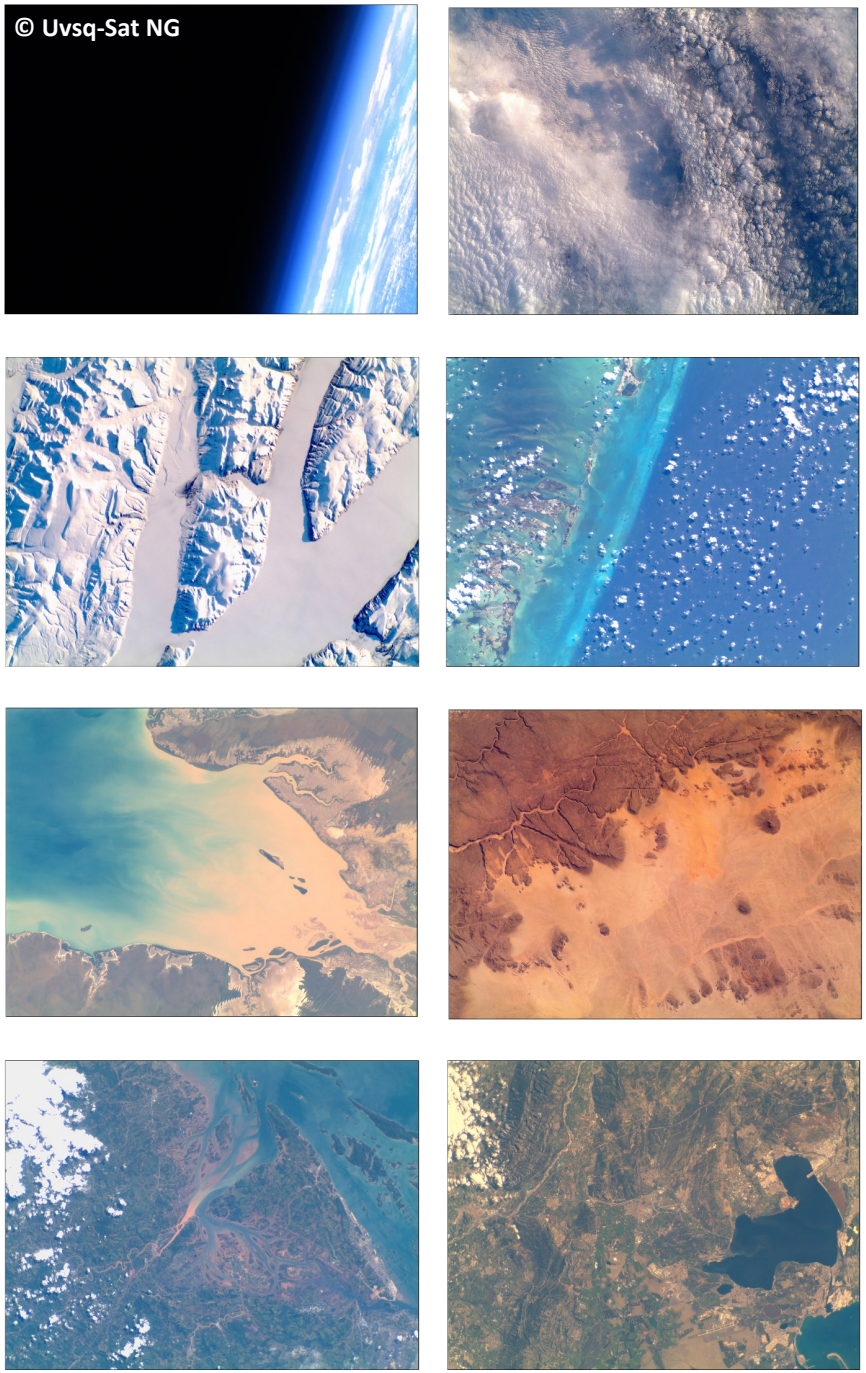
Complementing CERES Observations of Earth's Energy Imbalance with Uvsq-Sat and Inspire-Sat Small-Satellite Missions

Mustapha Meftah & Alain Sarkissian

LATMOS · UVSQ Université Paris-Saclay · CNRS · Sorbonne Université

Langley Research Center (LaRC) · Hampton · Oct 27-29, 2026



Outline

01 **Global & Scientific Objectives**
Why these missions · variables · performance · impact

02 **Satellite Mission Heritage**
Uvsq-Sat → Inspire-Sat 7 → Uvsq-Sat NG

03 **Uvsq-Sat NG**
Mission · payloads · observation geometries

04 **Results, Methods & Limits**
ERB · imaging · uncertainties

05 **Perspectives**
Short/long-term ERB science · constellation

06 **Conclusions**
Pathfinder evidence → climate observing system

01

Global and Scientific Objectives

Uvsq-Sat NG builds on Uvsq-Sat and Inspire-Sat 7 to advance **Earth Radiation Budget** (**ERB**) and **Greenhouse Gas** (**GHG**) observations, and to prepare future SmallSat constellations.

Science · Technology · Education · Innovation

SCIENCE

Earth and climate science using small satellites.

ERB · GHGs · atmospheric science · solar physics

TECHNOLOGY

Validate compact, low-power space instruments.

ERB sensors · NIR spectroscopy · imaging · Artificial Intelligence

EDUCATION & CAPACITY

Train students and engineers on real missions.

Mission design → AIT → operations → data exploitation

INNOVATION & NEWSPACE

Prepare scalable observing architectures.

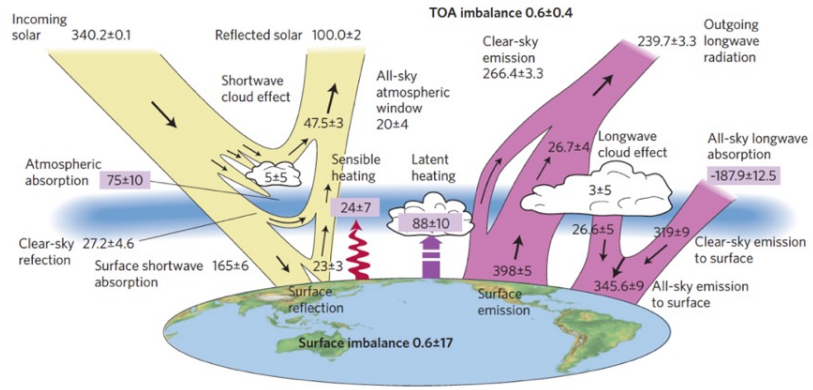
Industry · INSPIRE · Space Academy of Île-de-France* · future constellations

01

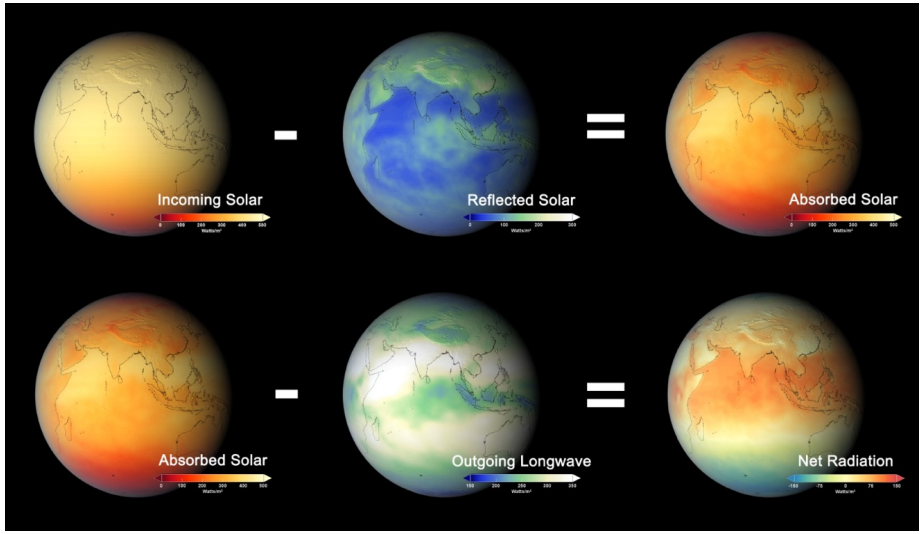
Why ERB Matter

ERB → Radiative response

ISR OSR OLR



Earth Energy Imbalance (EEI) = Incoming solar – [Reflected solar (OSR) + Outgoing longwave radiation (OLR)]



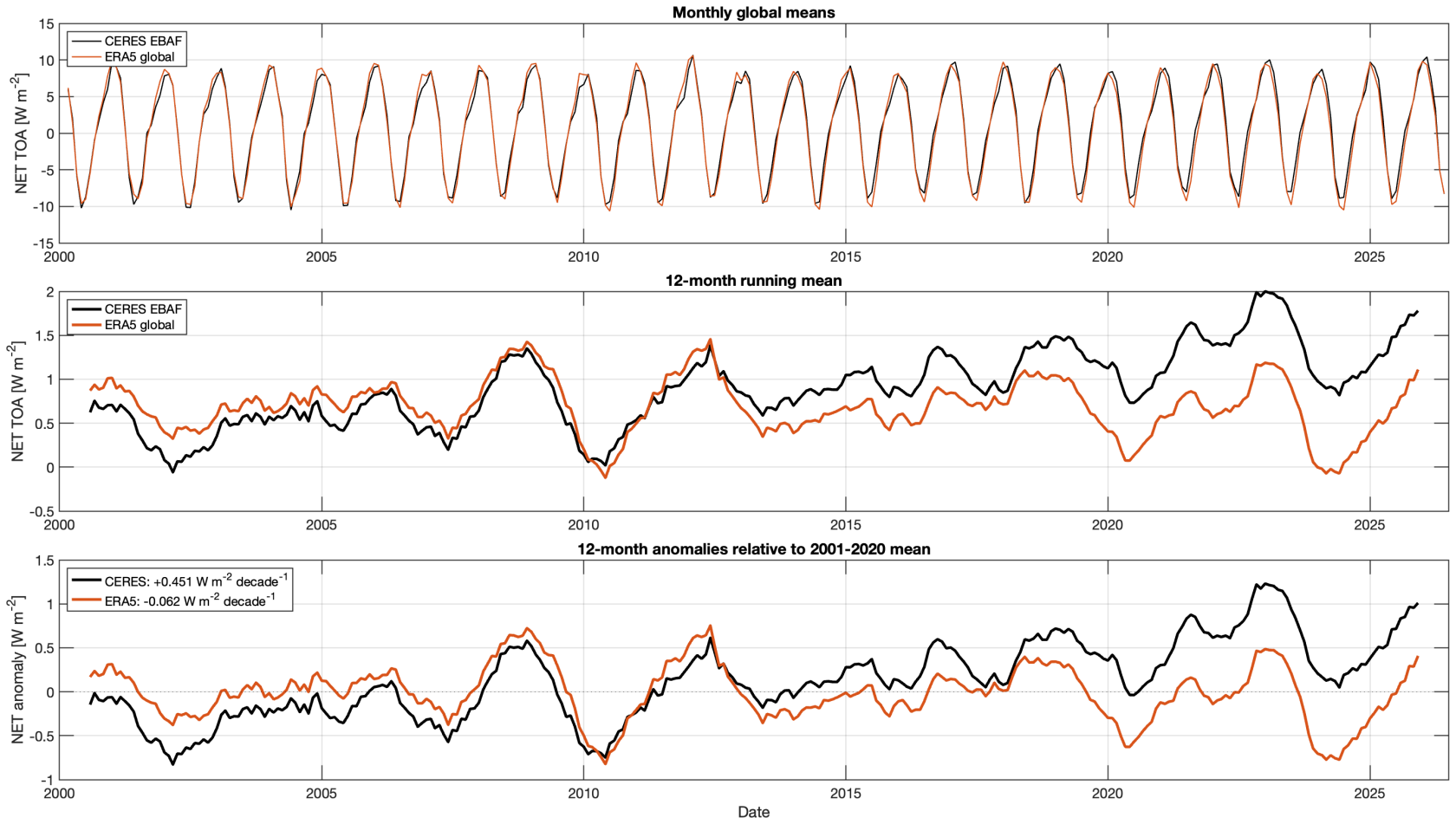
ERB scientific interest

EEI · planetary albedo · cloud/aerosol effects · radiative feedbacks · Earth-system energy storage

A single calibrated satellite contributes to climate continuity and validation; a constellation improves revisit and access to rapid processes.

01

Why ERB Matter



Increase in the net top-of-atmosphere radiative flux (NET) anomaly over 2001–2025 of $+0.451 \pm 0.196$ W m^{-2} decade^{-1} (95% confidence interval), with reduced reflected shortwave radiation providing the largest positive radiative contribution.

01

From One Pathfinder to N Satellites

ONE SATELLITE

Institutional reference missions

Role

- reference-quality observations
- climate-record continuity
- comparison / validation baseline

Key specifications

- OSR/OLR: ±1 W m^{-2} accuracy
- ERB spatial context: 10–25 km
- ERB stability: ±0.3–0.7 W m^{-2} $decade^{-1}$

- XCO_2: ±1 ppm objective
- XCH_4: ±10 ppb objective
- GHG spatial context: 1–10 km

Revisit: ~24 h for wide-swath missions • **up to ~20 days** for narrow-swath CO_2 missions

Uvsq-Sat NG PATHFINDER

Compact mission capability

Role

- miniaturized ERB/GHG pathfinder
- calibration and stability tests
- retrieval and error-budget validation

Key specifications

- OSR/OLR: ±3 W m^{-2} accuracy
- ERB spatial context: 1000 km
- ERB stability: ±1 W m^{-2} $decade^{-1}$

- XCO_2: ±4 ppm objective
- XCH_4: ±25 ppb objective
- GHG spatial context: 2–10 km

Revisit: ~2–3 days, latitude dependent • targeted observations for narrow FOV

N-SATELLITE CONSTELLATION

Climate-observing target

Role

- revisit and local-time diversity
- diurnal-cycle sampling
- redundancy and continuity

Key specifications

- OSR/OLR: ±0.2 W m^{-2} goal
- ERB spatial context: 10–100 km
- ERB stability: ±0.05–0.06 W m^{-2} $decade^{-1}$

- XCO_2: ±0.6 ppm objective
- XCH_4: ±7 ppb objective
- GHG spatial context: ≤1 km

Target revisit: ~3 h requires wide effective swath / scanning

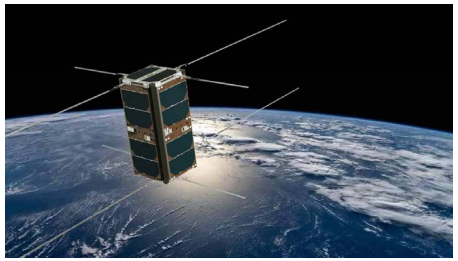
Pathfinder measurements validate the concept;
high-revisit architectures extend it to rapid-process and climate science.

02

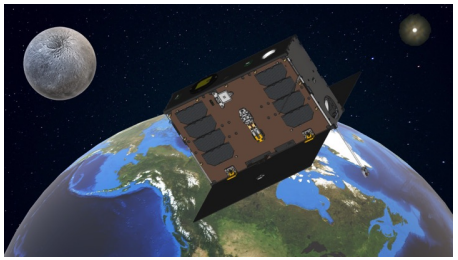
Satellite Mission Heritage: A Stepwise Scientific Program



Increasing capability



Increasing capability



Uvsq-Sat (Inspire-Sat 5)

Studies + Manufacturing | Tests | Operations | Data exploitation

2018 — 1 — 2 — 24/01/2021 — 3 — 13/03/2021 — End of Life 24/10/2024 — 4

Uvsq-Sat+ (Inspire-Sat 7)

Studies + Manufacturing | Tests | Operations | Data exploitation

2020 — 1 — 2 — 15/04/2023 — 3 — 15/05/2023 — End of Life 15/09/2024 — 4

Uvsq-Sat NG (Inspire-Sat X)

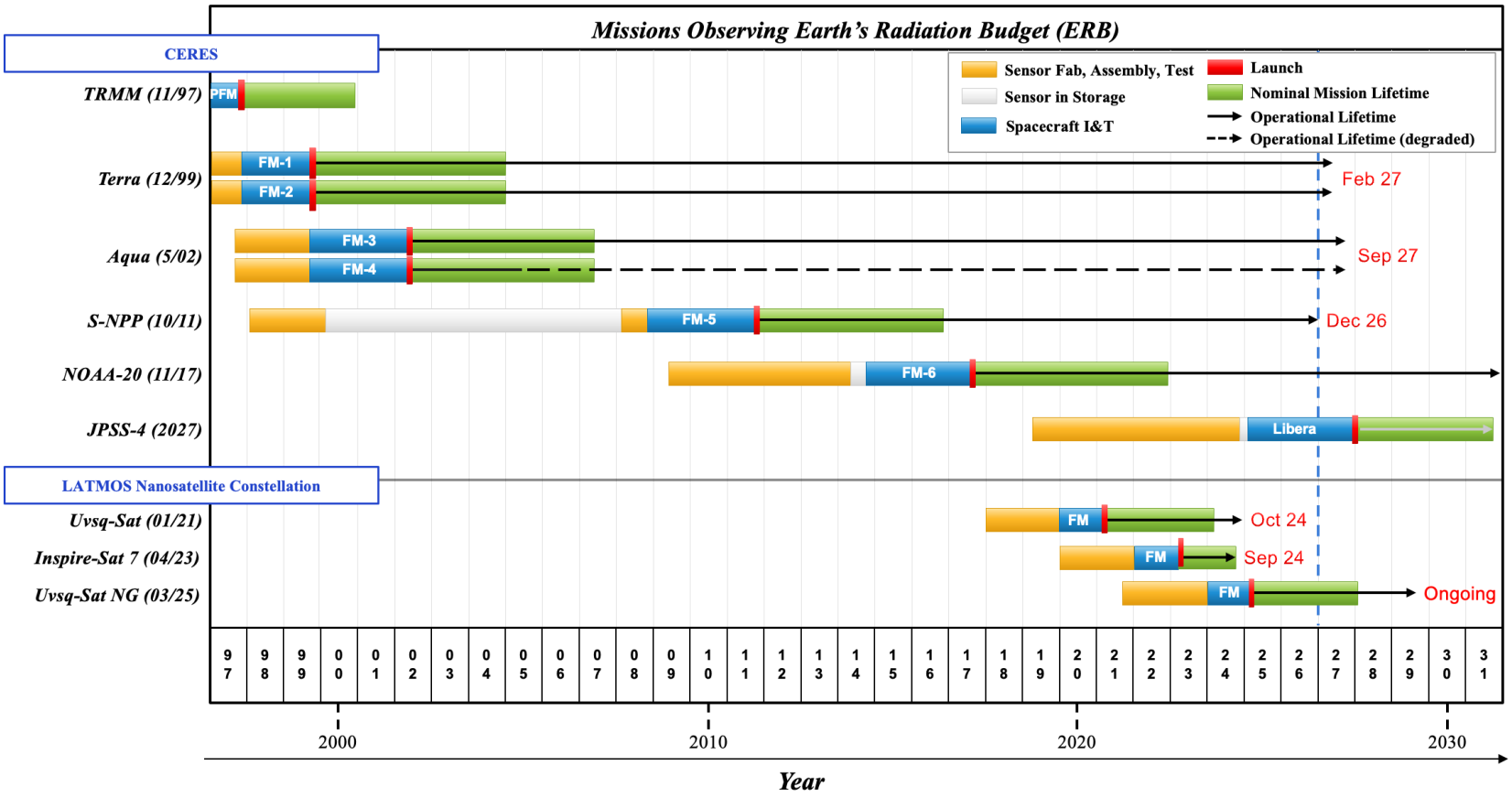
Studies + Manufacturing | Tests | Operations | Data exploitation

2021 — 1 — 2 — 15/03/2025 — ? — End of Life — 4

Phases 0/A, B, C, D | Phase E | Phase F

02

Satellite Mission Heritage and Demonstrated Results



Published ERB anchor

Uvsq-Sat/Inspire-Sat observations showed consistency with CERES over 2021–2024; the published Uvsq-Sat-based EEI estimate is:

EEI = +0.87 ± 0.23 W m^{-2}

SmallSats complement reference climate missions.

03

Uvsq-Sat NG: A Multi-Observable Climate Pathfinder

MISSION

Launch: 15 March 2025
Orbit: ~600 km SSO
Platform: 6U CubeSat
M/P: 10 kg / 25 W

SCIENCE

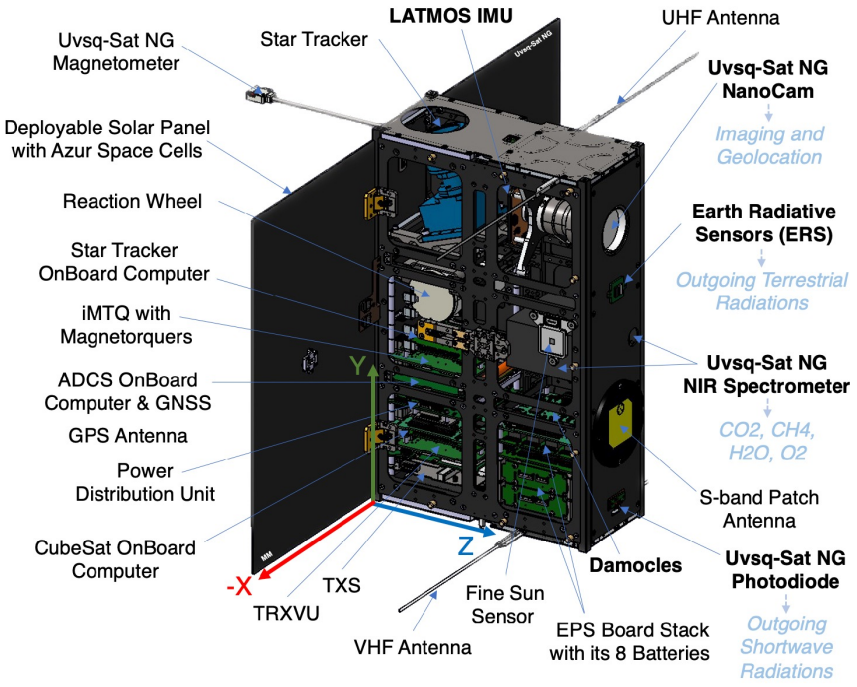
ERB + GHG + atmosphere / surface context within one architecture.

POINTING

Nadir, glint, limb, scan and solar-occultation observations.

OPERATIONS

Flexible mission planning and distributed ground segment.



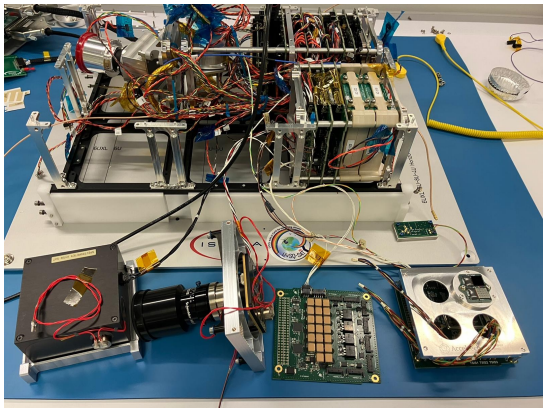
Role: test measurements, observation geometries and calibration strategies for the next observing architecture.

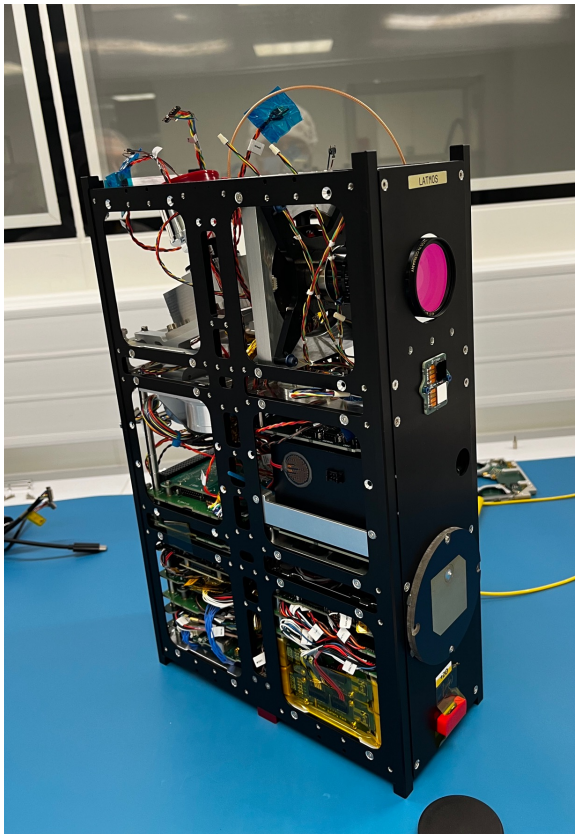
Multi-observable mission

03

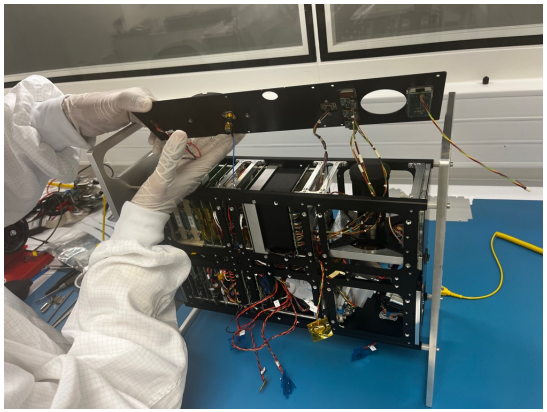
Uvsq-Sat NG: A Multi-Observable Climate Pathfinder

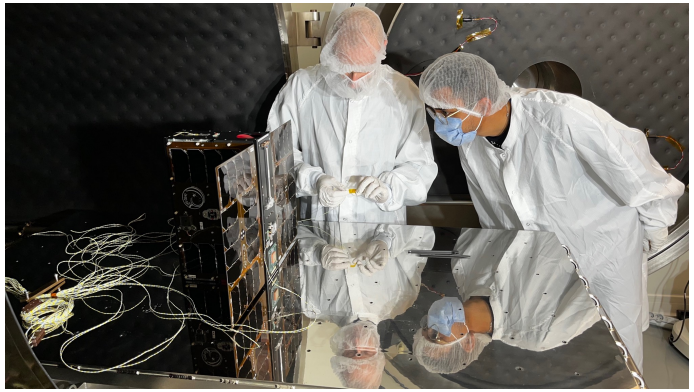
Uvsq-Sat NG is a fully in-house mission: our team secured the funding and controls the entire end-to-end chain, from scientific definition and spacecraft development to launch, operations and data exploitation.







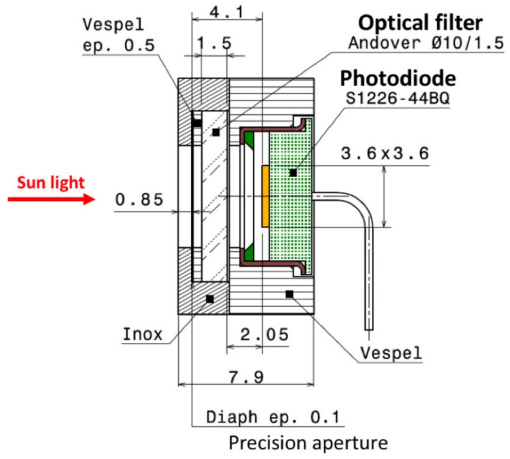


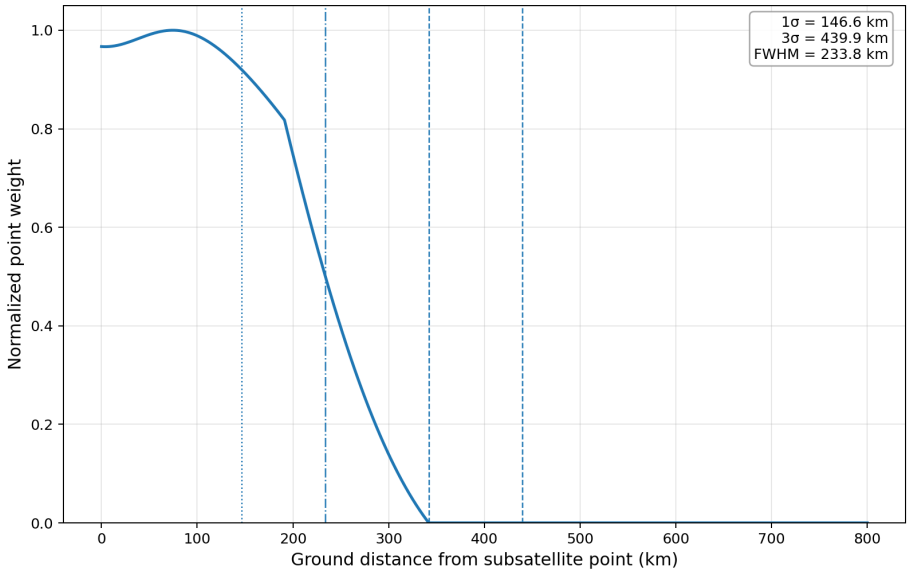


03

Local ground-point weight

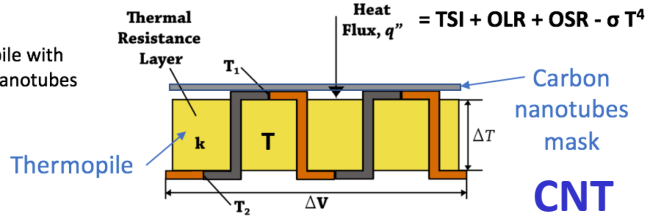
TSIS



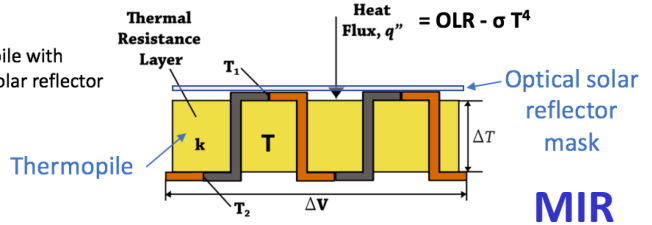


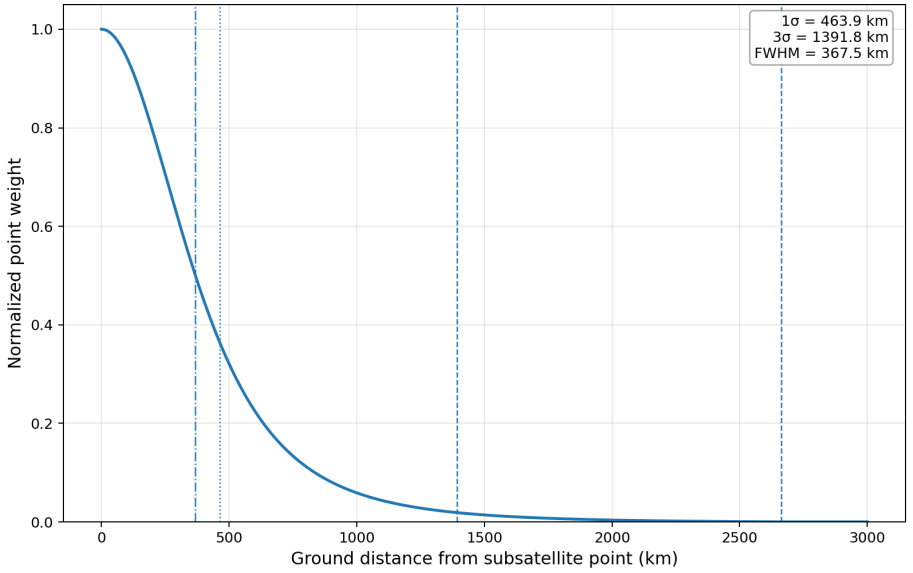
ERS

ERS
Thermopile with carbon nanotubes



ERS
Thermopile with optical solar reflector

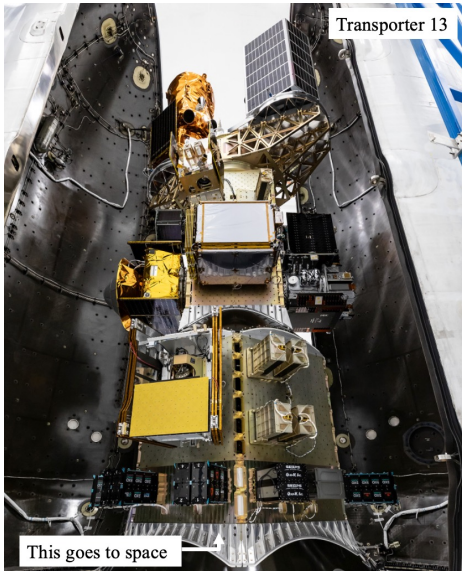




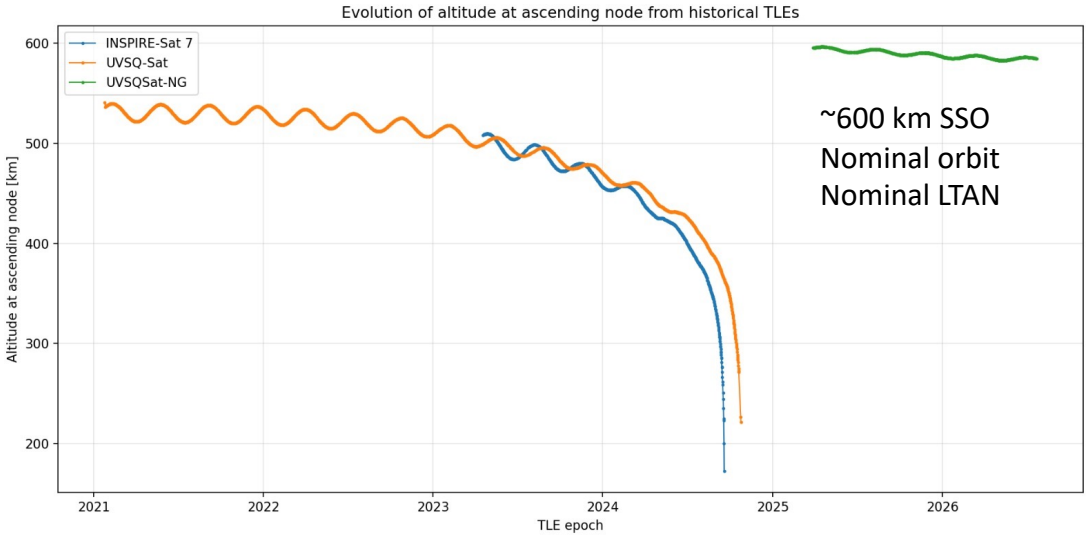
04

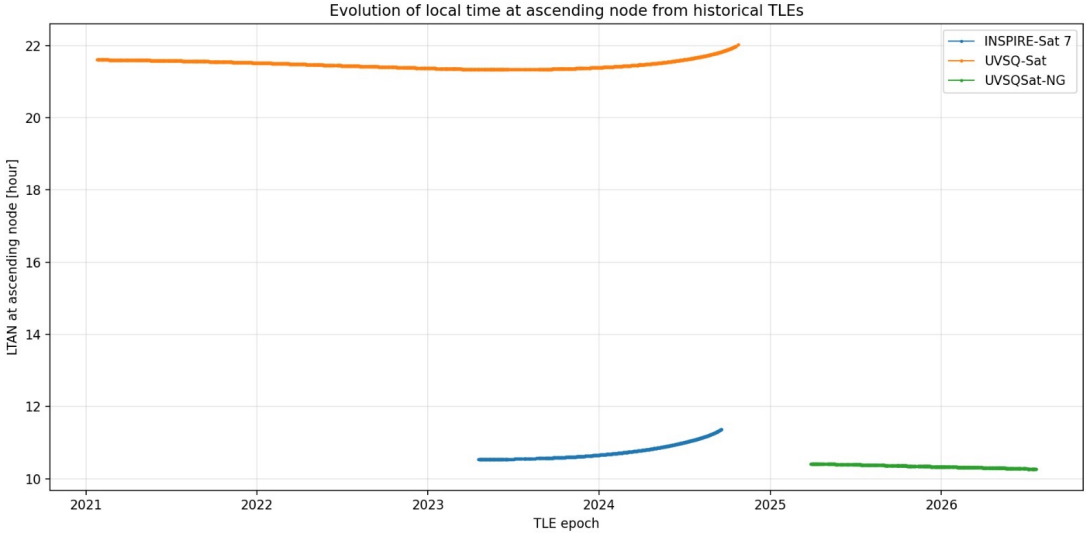
Results, Methods & Limits

❑ Orbit evolution and LTAN





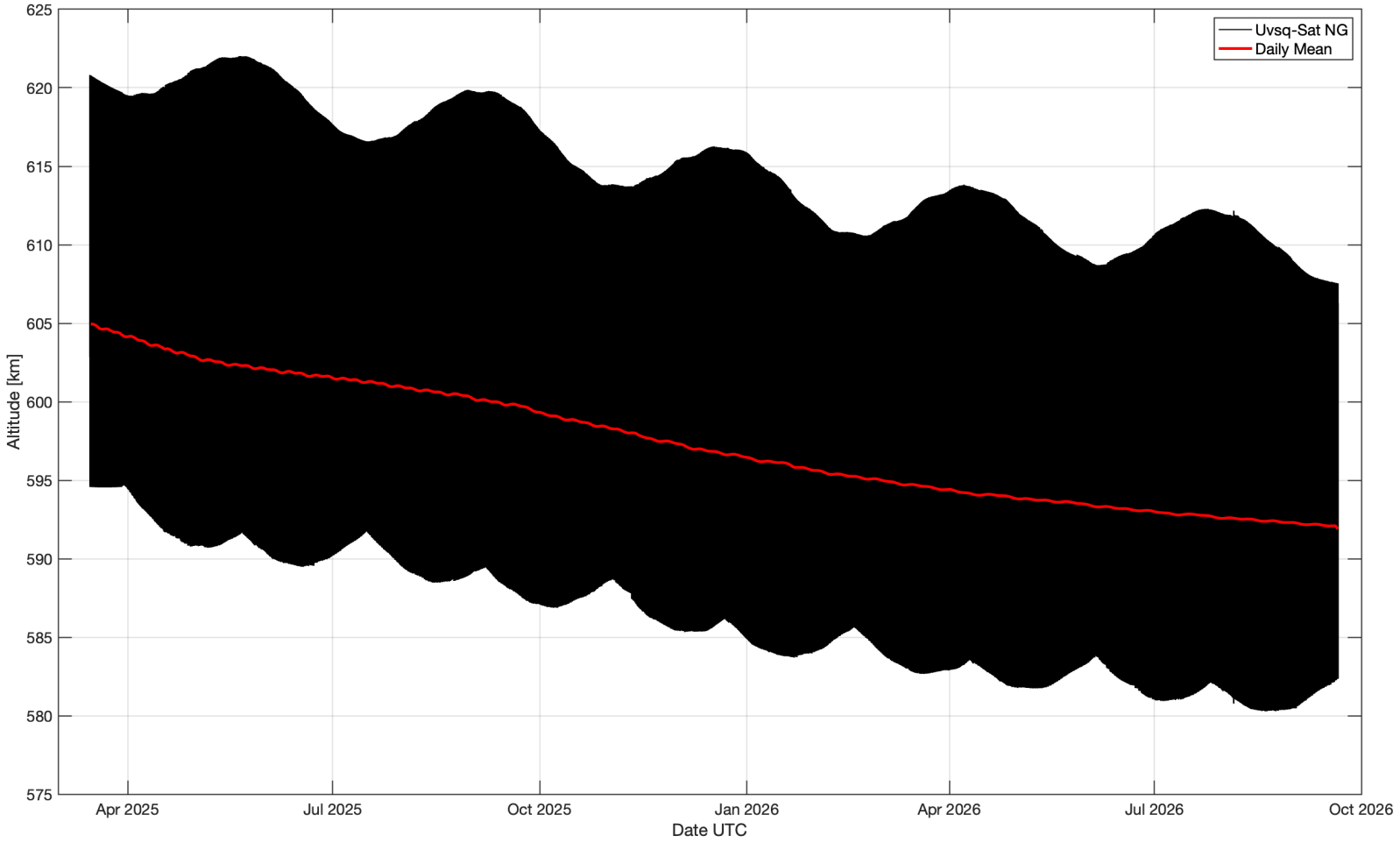




04

Results, Methods & Limits

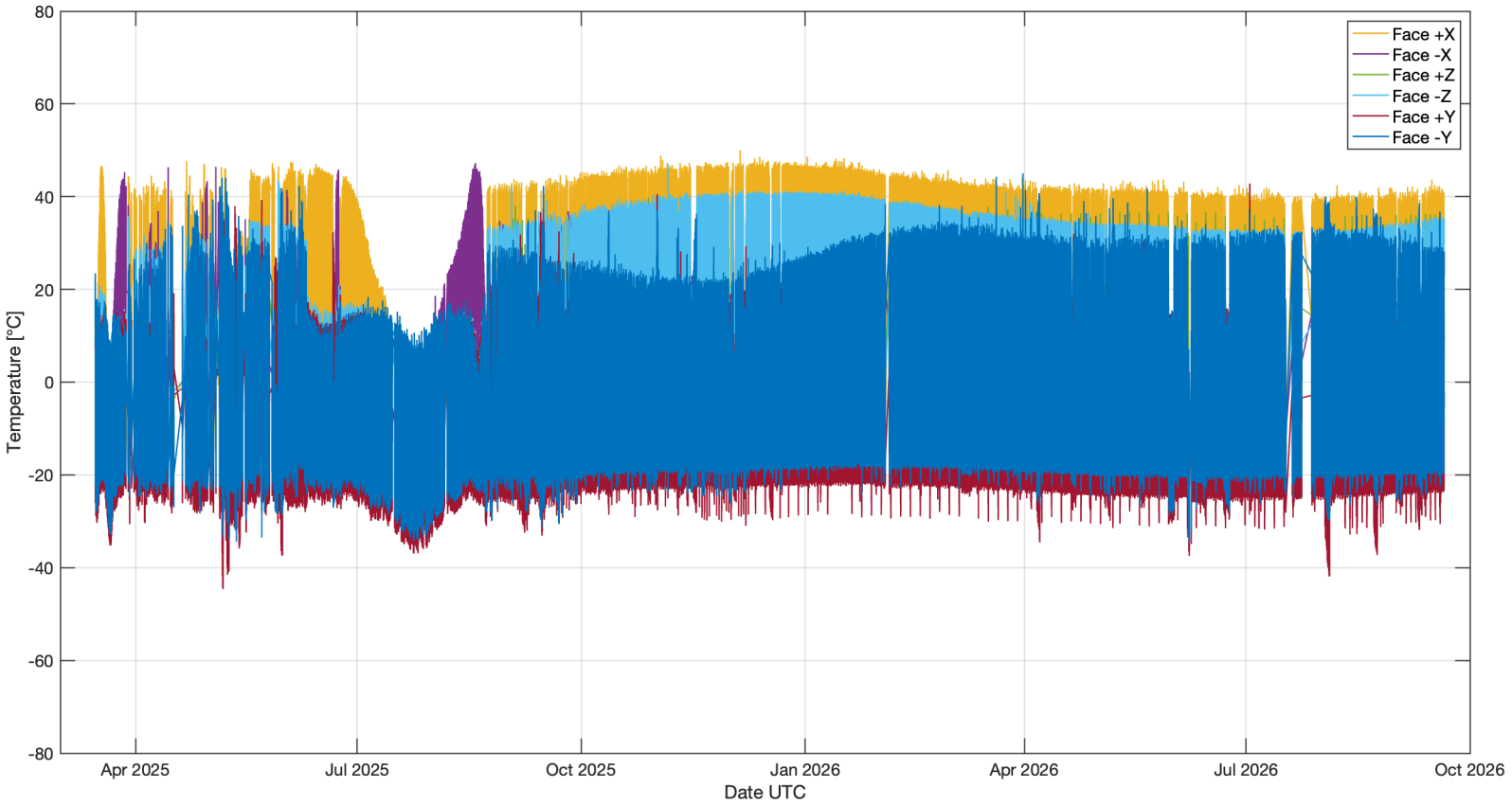
❑ Orbit evolution and LTAN



04

Results, Methods & Limits

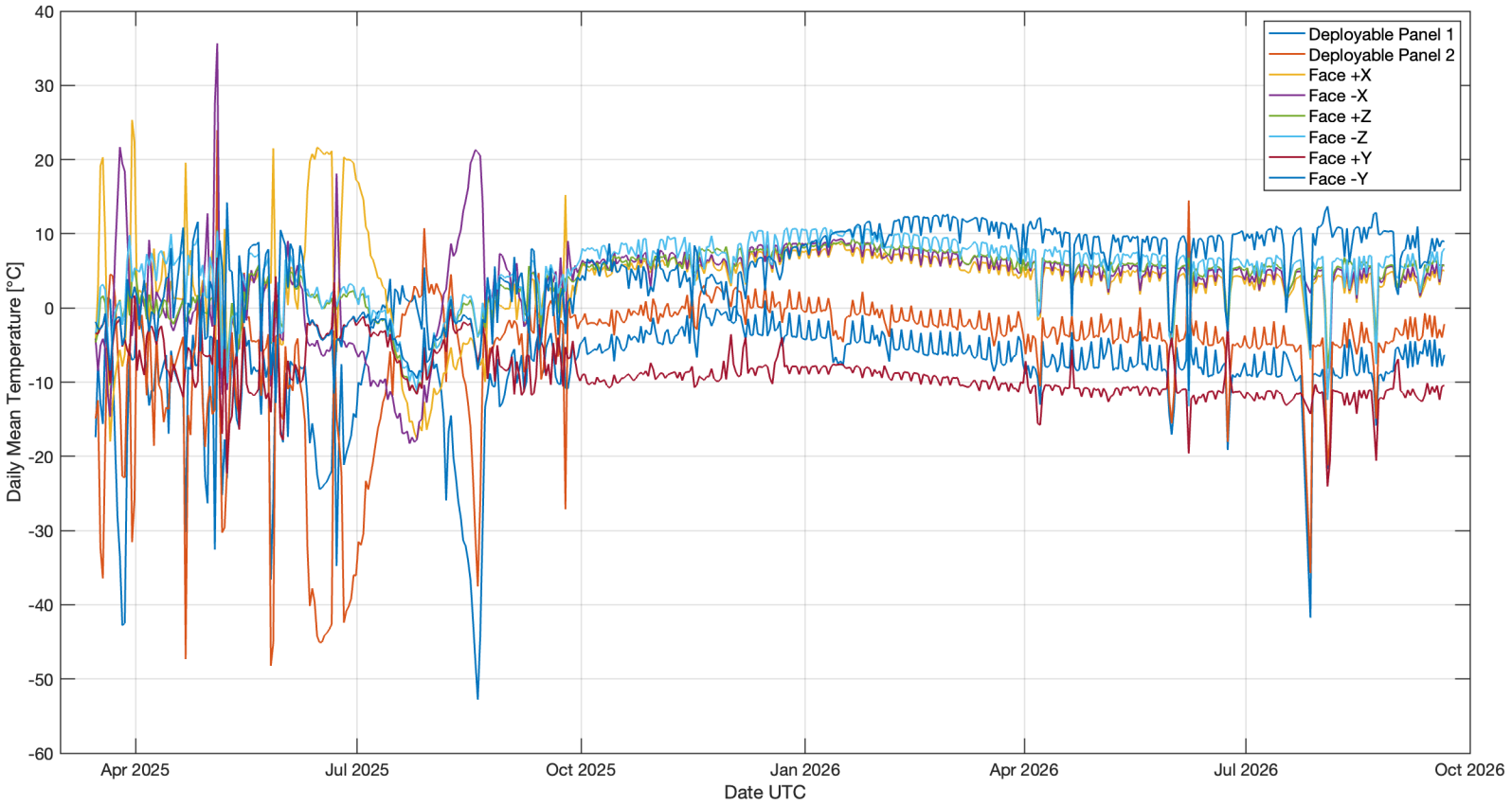
❑ Temperatures



04

Results, Methods & Limits

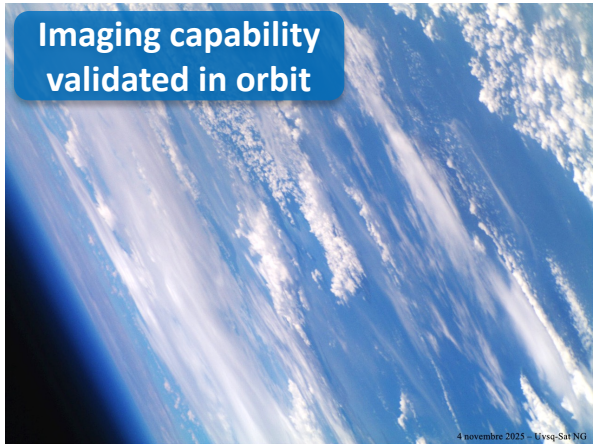
❑ Temperatures

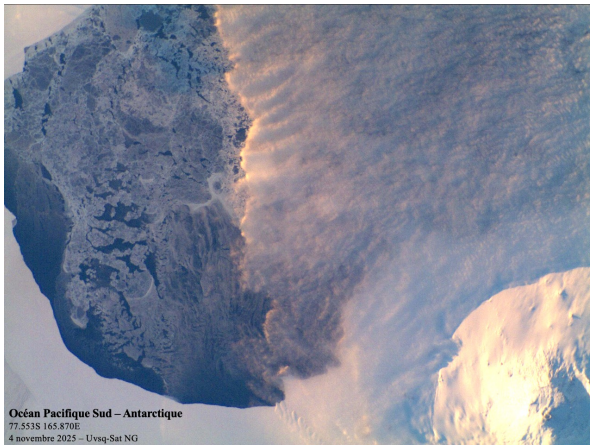


04

Results, Methods & Limits

❑ Imaging — in-orbit performance





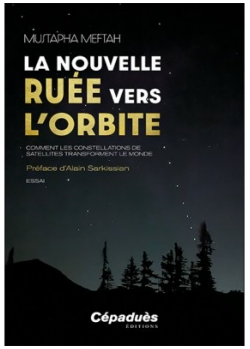






Books published in 2026

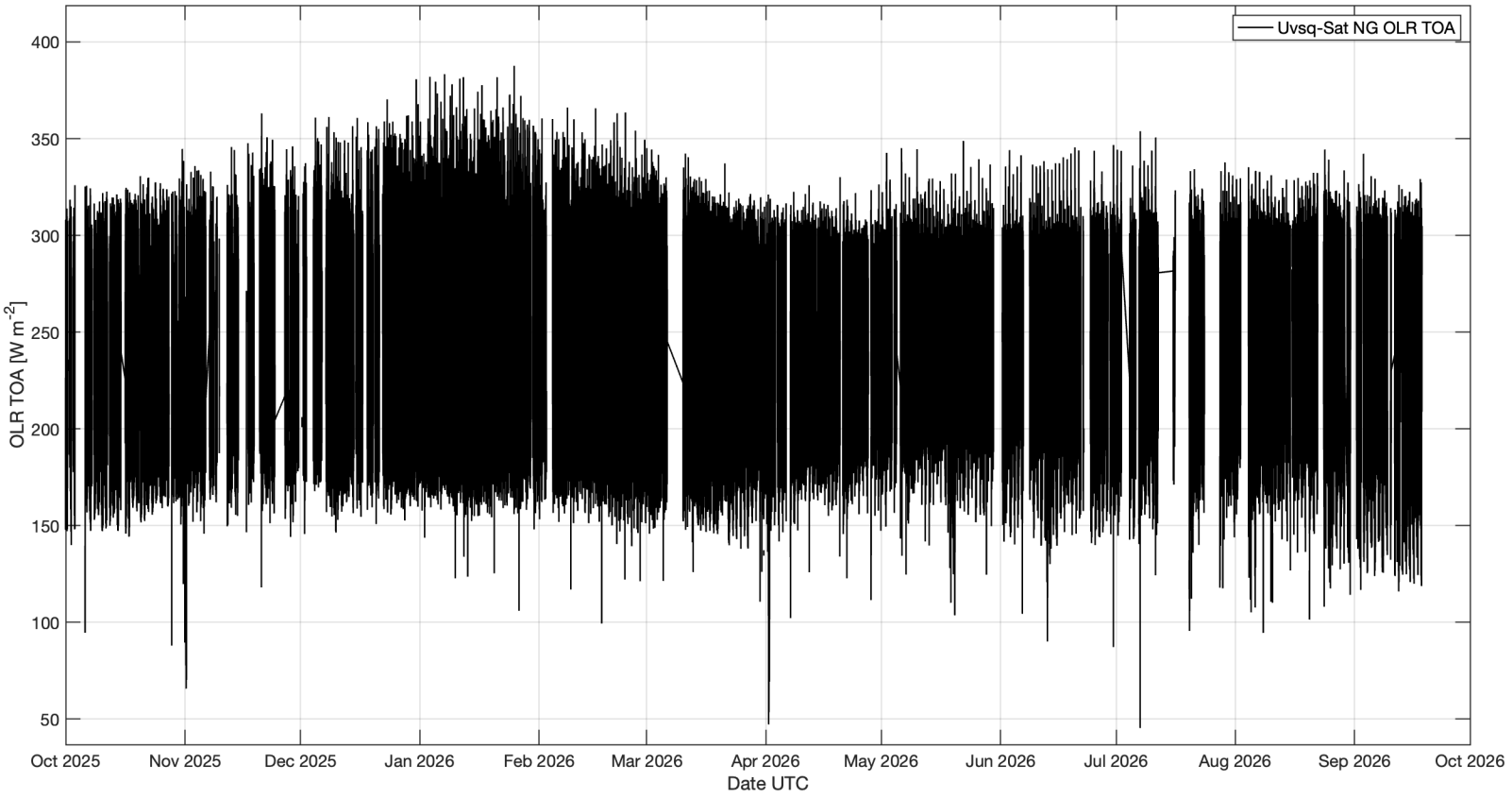




04

Results, Methods & Limits

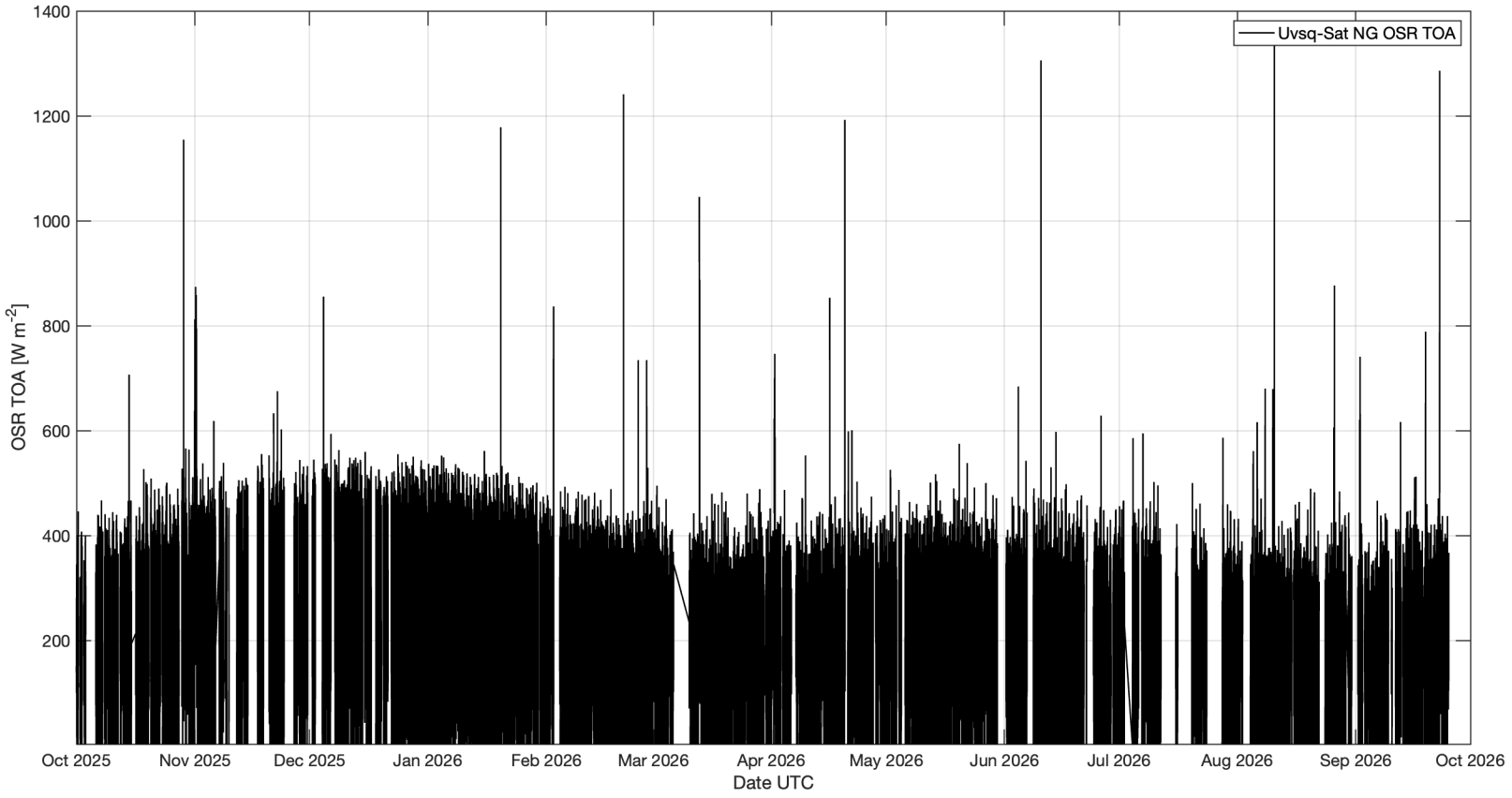
❑ ERB — Uvsq-Sat NG OLR timeseries



04

Results, Methods & Limits

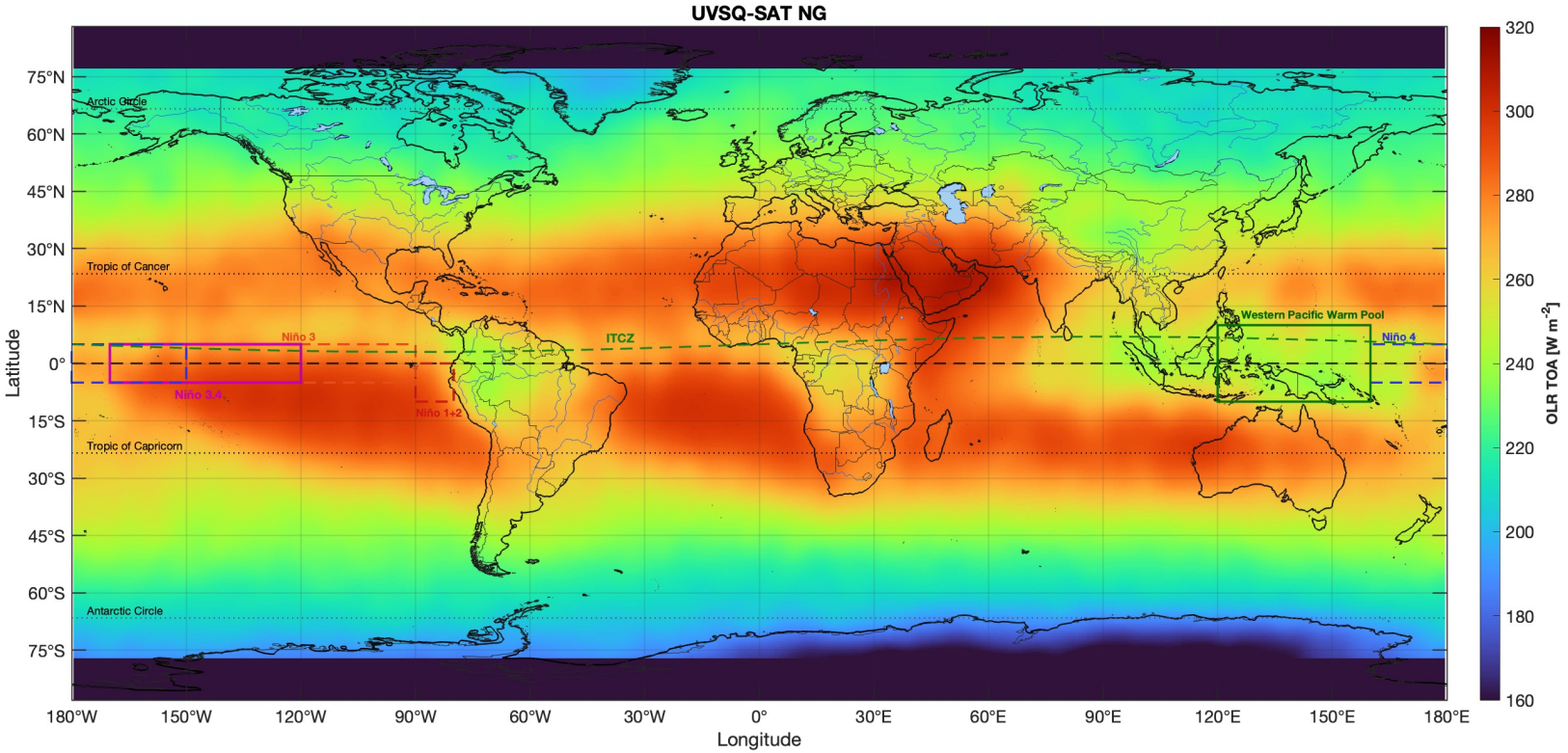
❑ ERB — Uvsq-Sat NG OSR timeseries



04

Results, Methods & Limits

❑ ERB — Uvsq-Sat NG OLR map reconstruction

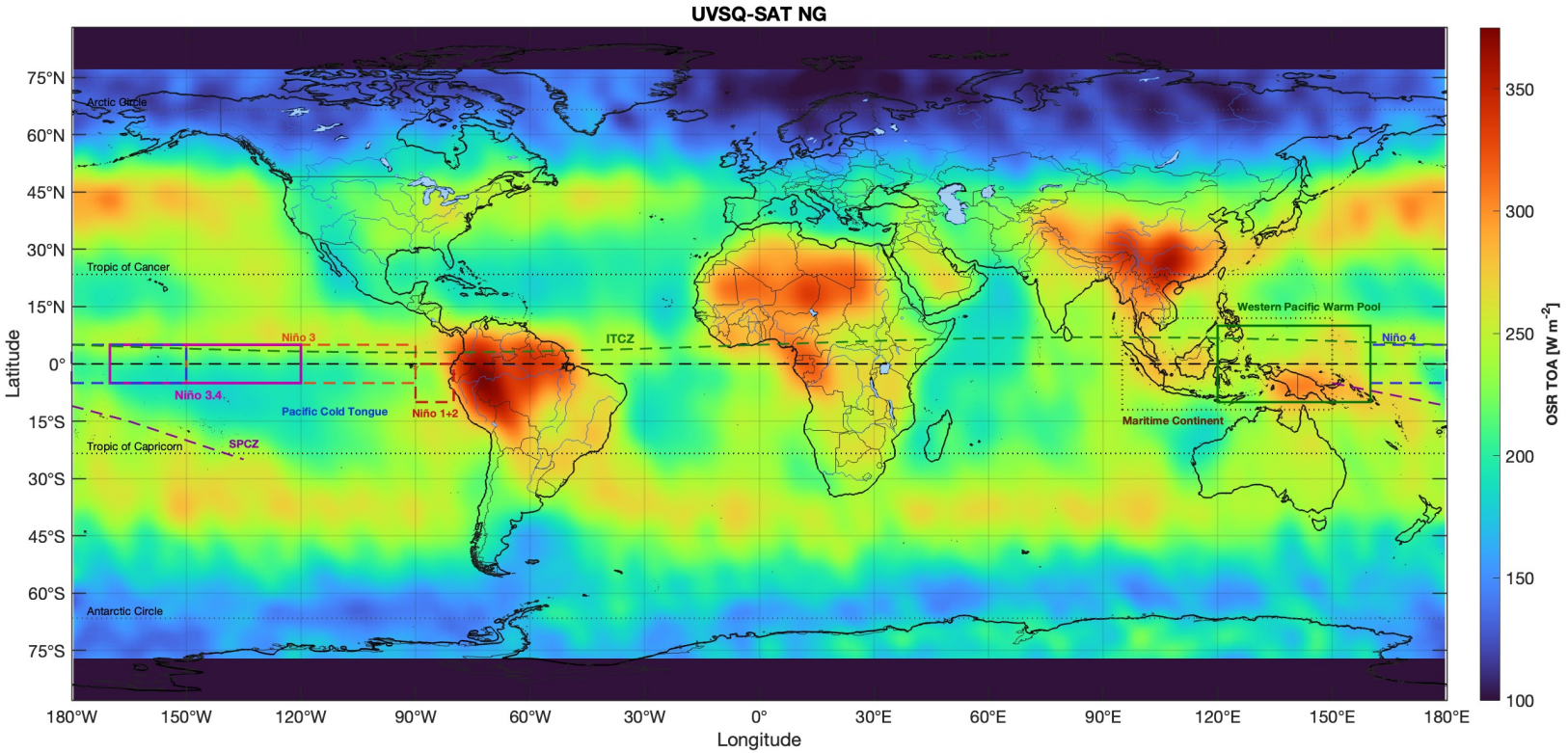


Global radiative fields constructed from UVSQ-SAT NG observations accumulated between March 2025 and September 2026.

04

Results, Methods & Limits

❑ ERB — Uvsq-Sat NG OSR map reconstruction

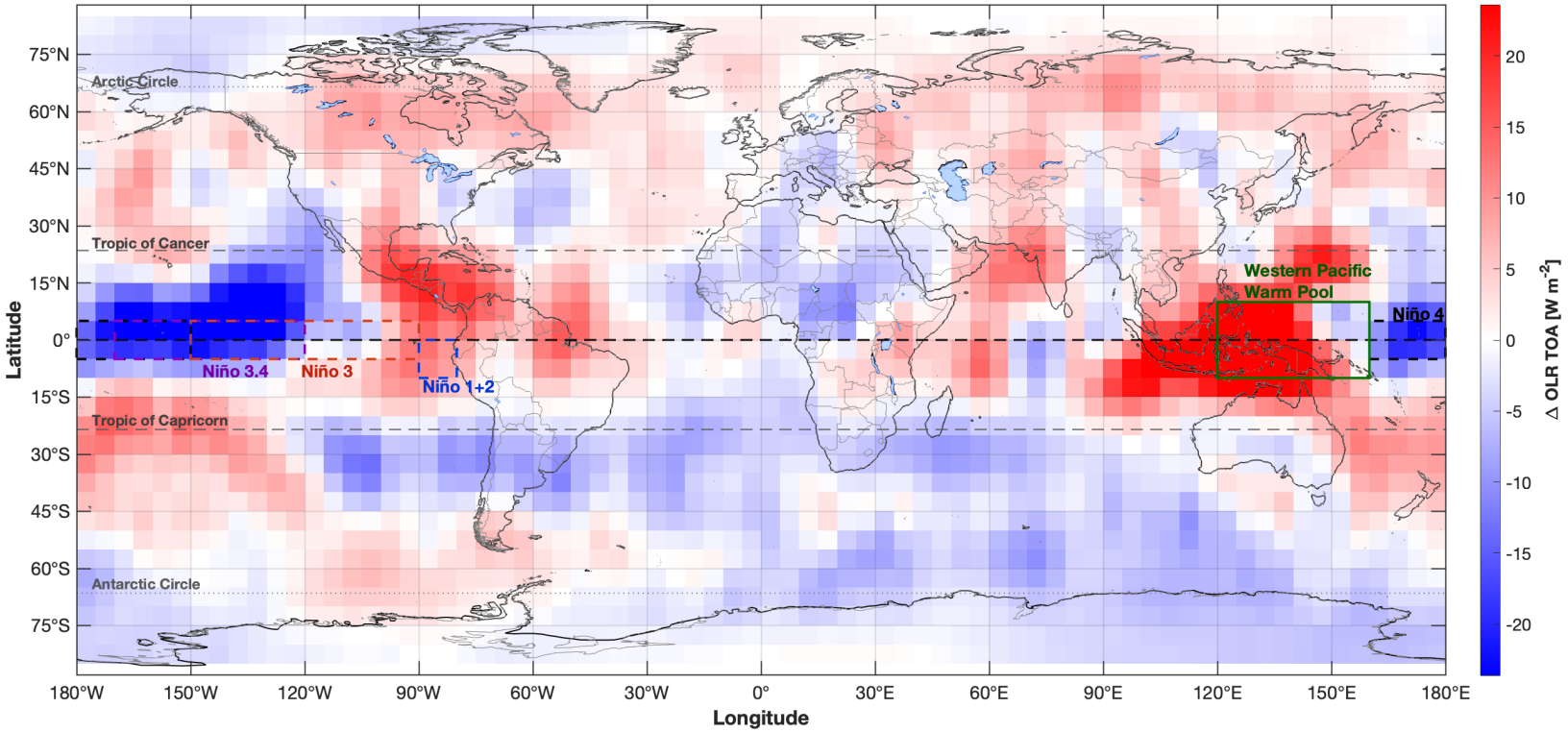


Global radiative fields constructed from UVSQ-SAT NG observations accumulated between March 2025 and September 2026.

04

Results, Methods & Limits

❑ **ERB — OLR Spatial radiative reorganization from JJA 2025 to JJA 2026**

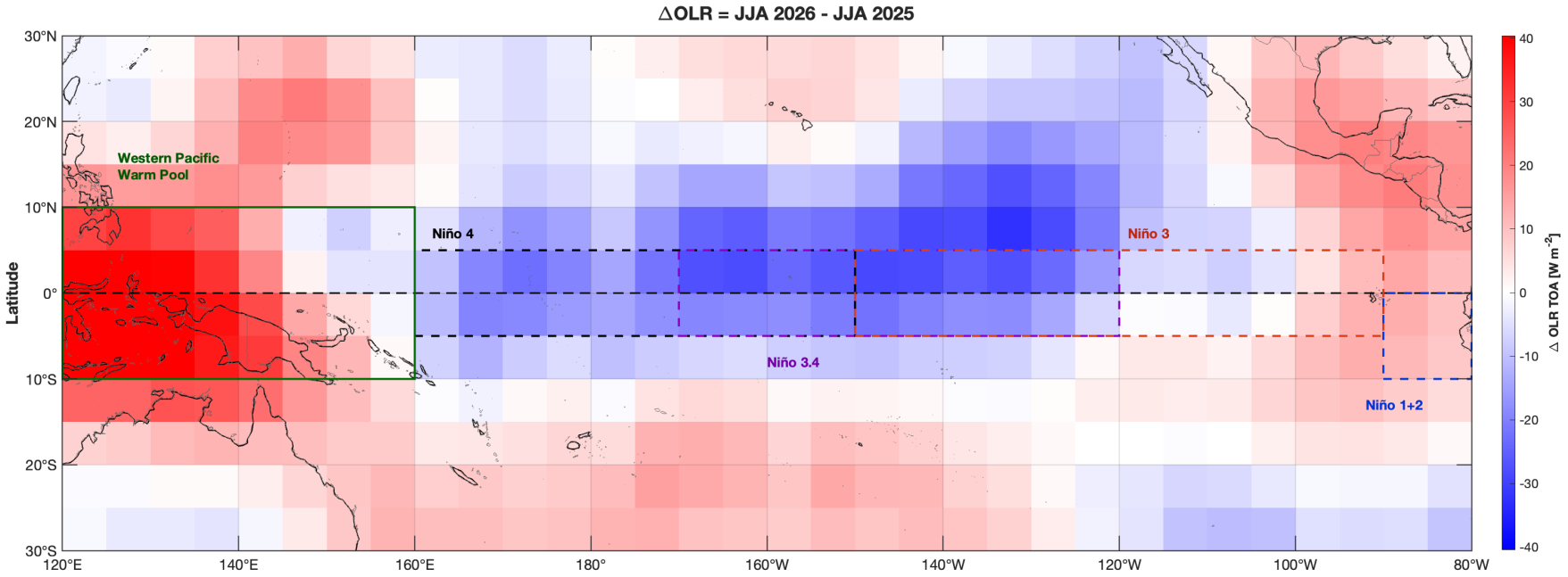


The maps highlight the zonal contrast across the equatorial Pacific during the development of the 2026 El Nino.

04

Results, Methods & Limits

❑ ERB — Tropical OLR evolution from JJA 2025 to JJA 2026

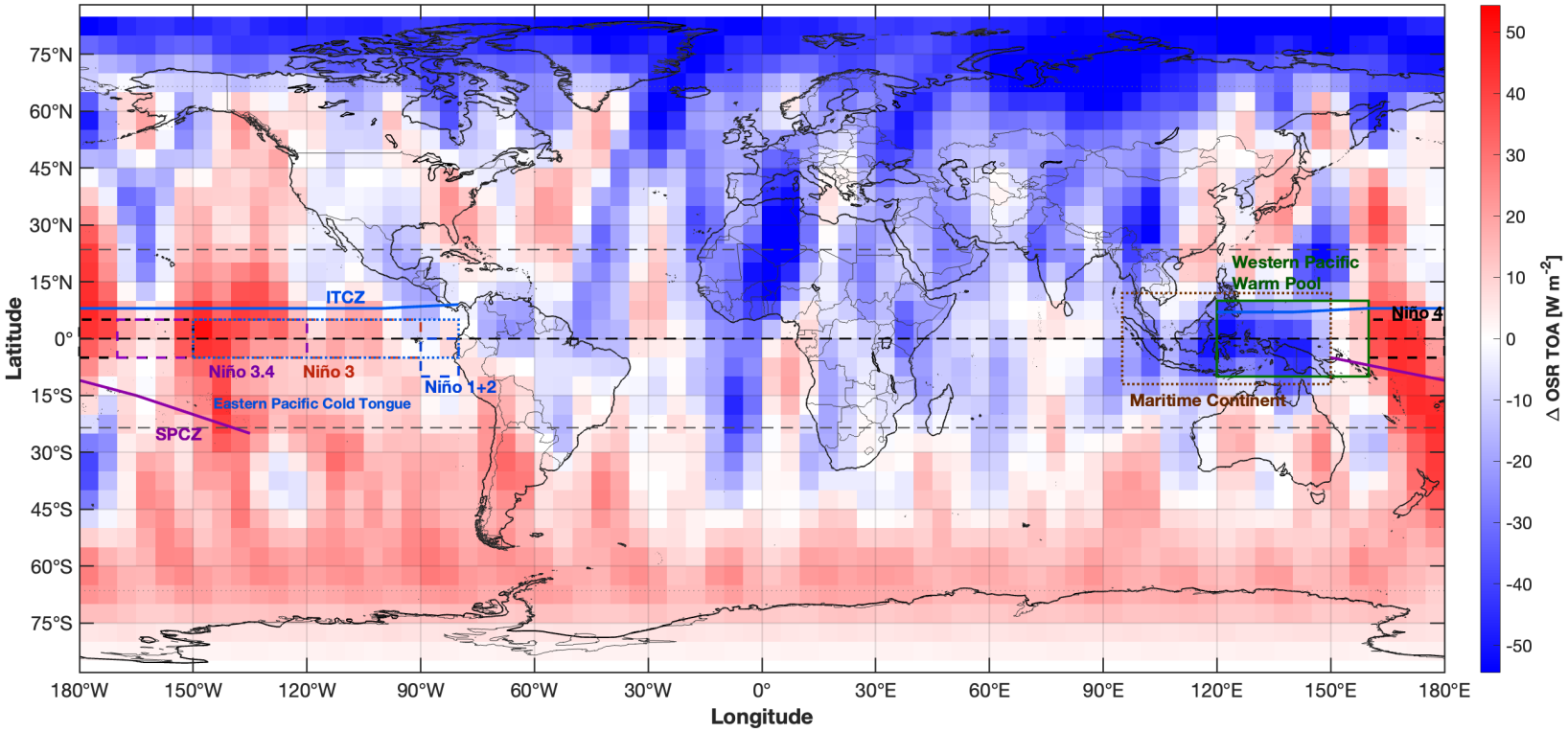


- **Western Pacific**: Strong OLR increase (up to +40 W m^{-2}), consistent with reduced deep convection and high-cloud cover.
- **Central Pacific**: Pronounced OLR decrease (down to −35 W m^{-2}), suggesting enhanced convection and colder cloud tops.
- **Spatial pattern**: A marked west–central Pacific contrast, with negative anomalies extending northward toward the Intertropical Convergence Zone (ITCZ).
- **Physical interpretation**: Consistent with an eastward redistribution of tropical convection, potentially associated with changes in the Pacific Walker circulation.

04

Results, Methods & Limits

❑ ERB — OSR Spatial radiative reorganization from JJA 2025 to JJA 2026

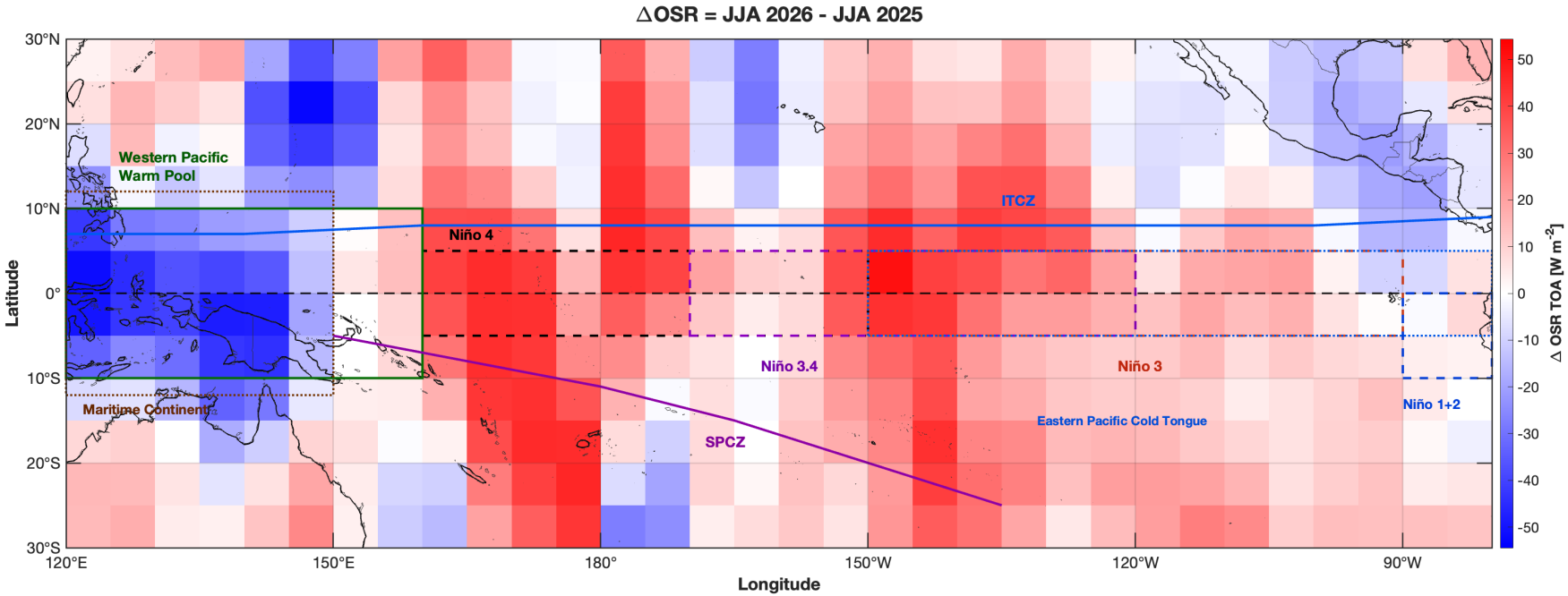


The maps highlight the zonal contrast across the equatorial Pacific during the development of the 2026 El Nino.

04

Results, Methods & Limits

❑ ERB — Tropical OSR evolution from JJA 2025 to JJA 2026

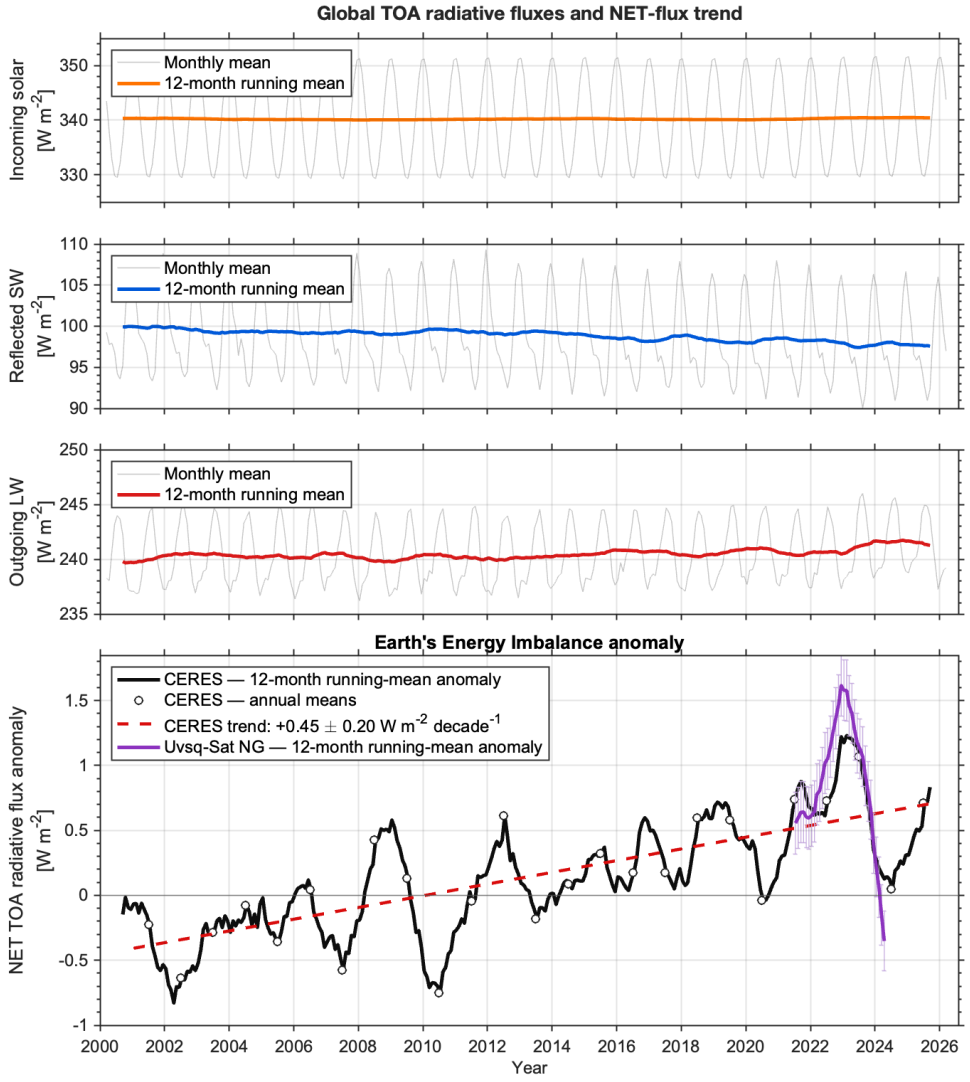


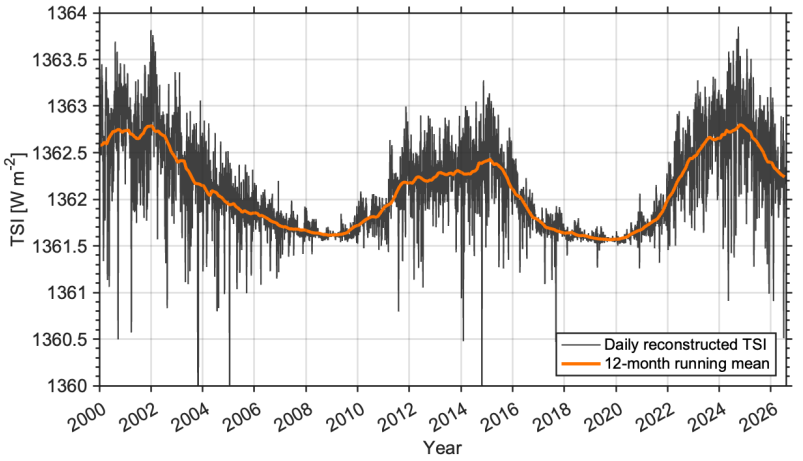
- **Western Pacific**: Strong OSR decrease (locally below −40 W m^{-2}), consistent with reduced cloud reflection.
- **Central Pacific**: Pronounced OSR increase (up to +40–50 W m^{-2}), suggesting enhanced cloud reflectivity.
- **Spatial pattern**: A west–central Pacific contrast broadly opposite to OLR, involving the Intertropical Convergence Zone (ITCZ) and South Pacific Convergence Zone (SPCZ).
- **Physical interpretation**: Consistent with changes in tropical cloud distribution and convection, potentially linked to a reorganization of the Walker circulation.

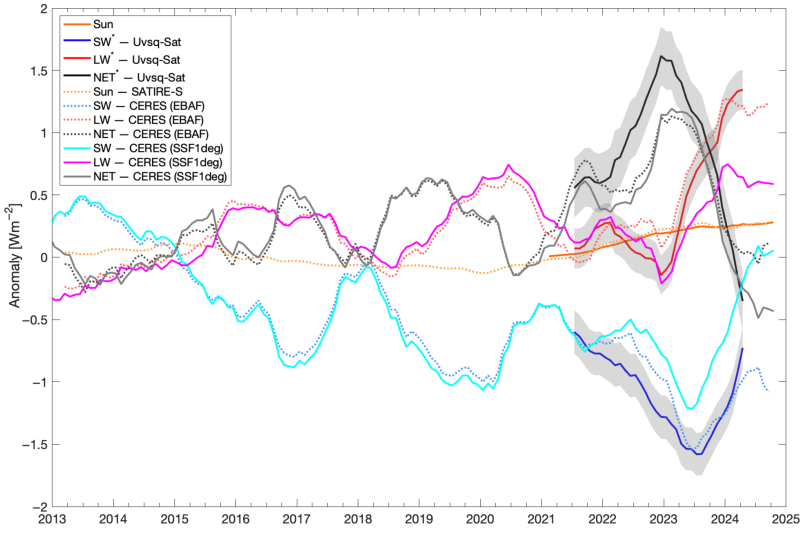
04

Results, Methods & Limits

❑ ERB — preliminary in-orbit results for the Uvsq-Sat constellation



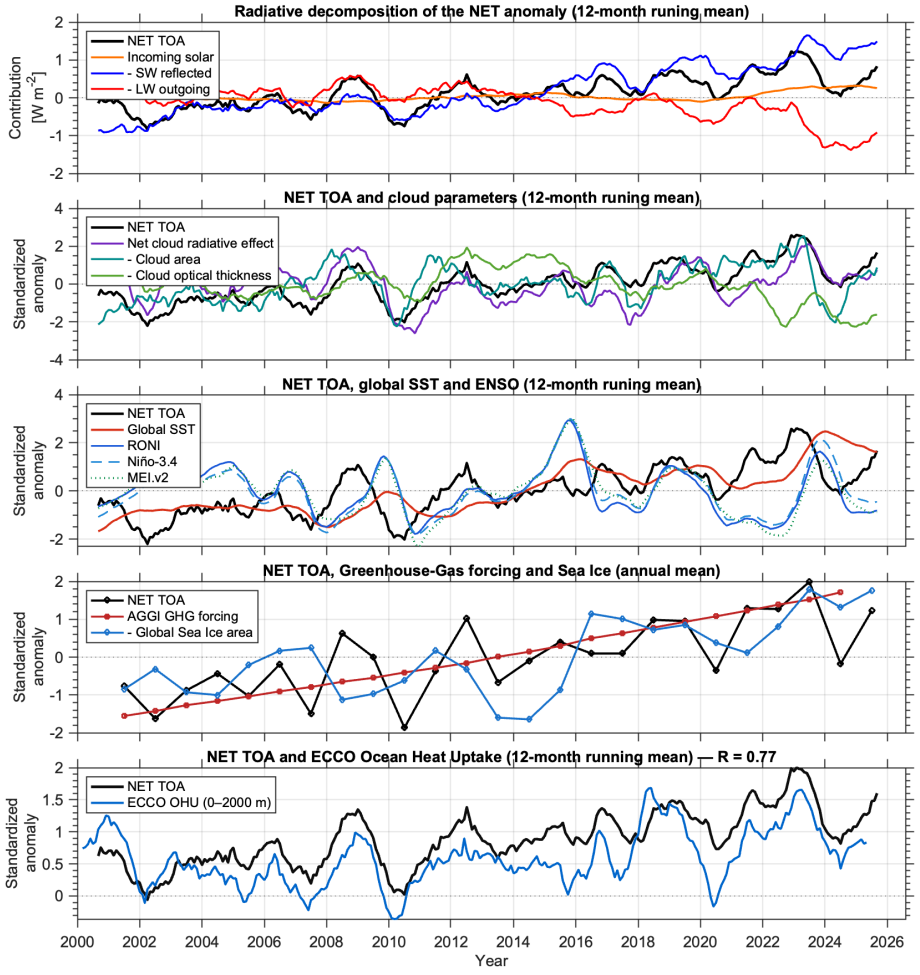


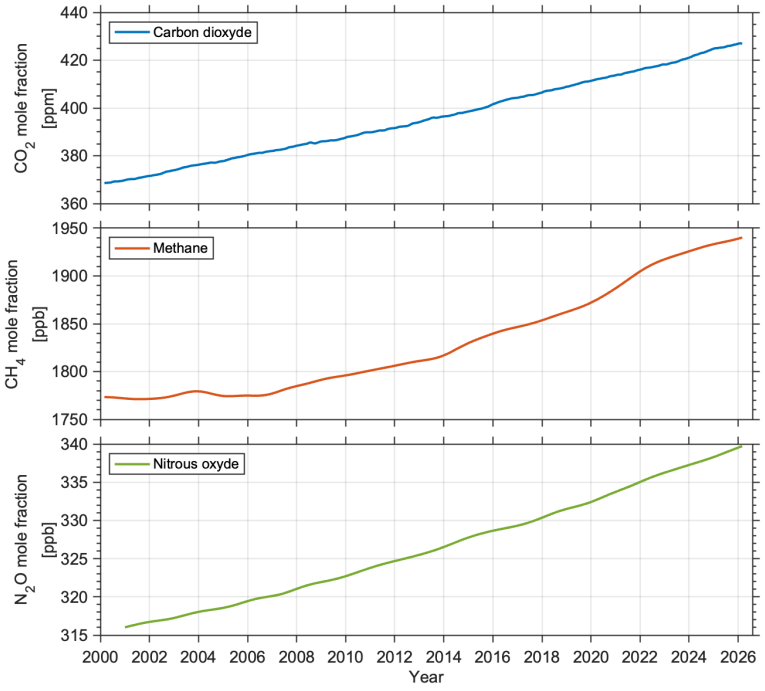


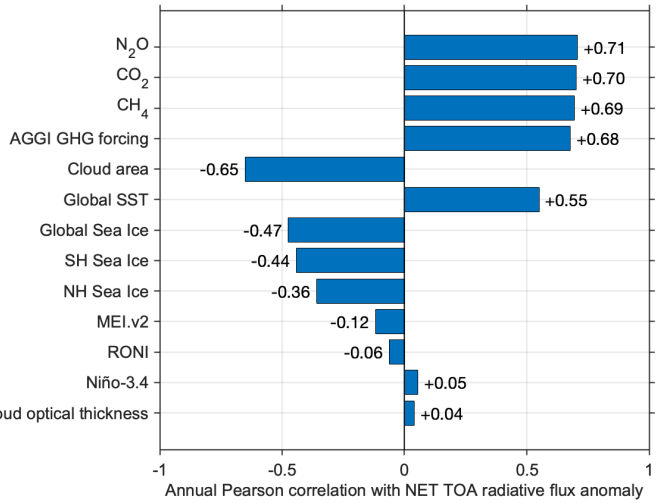
04

Results, Methods & Limits

❑ ERB — preliminary analysis

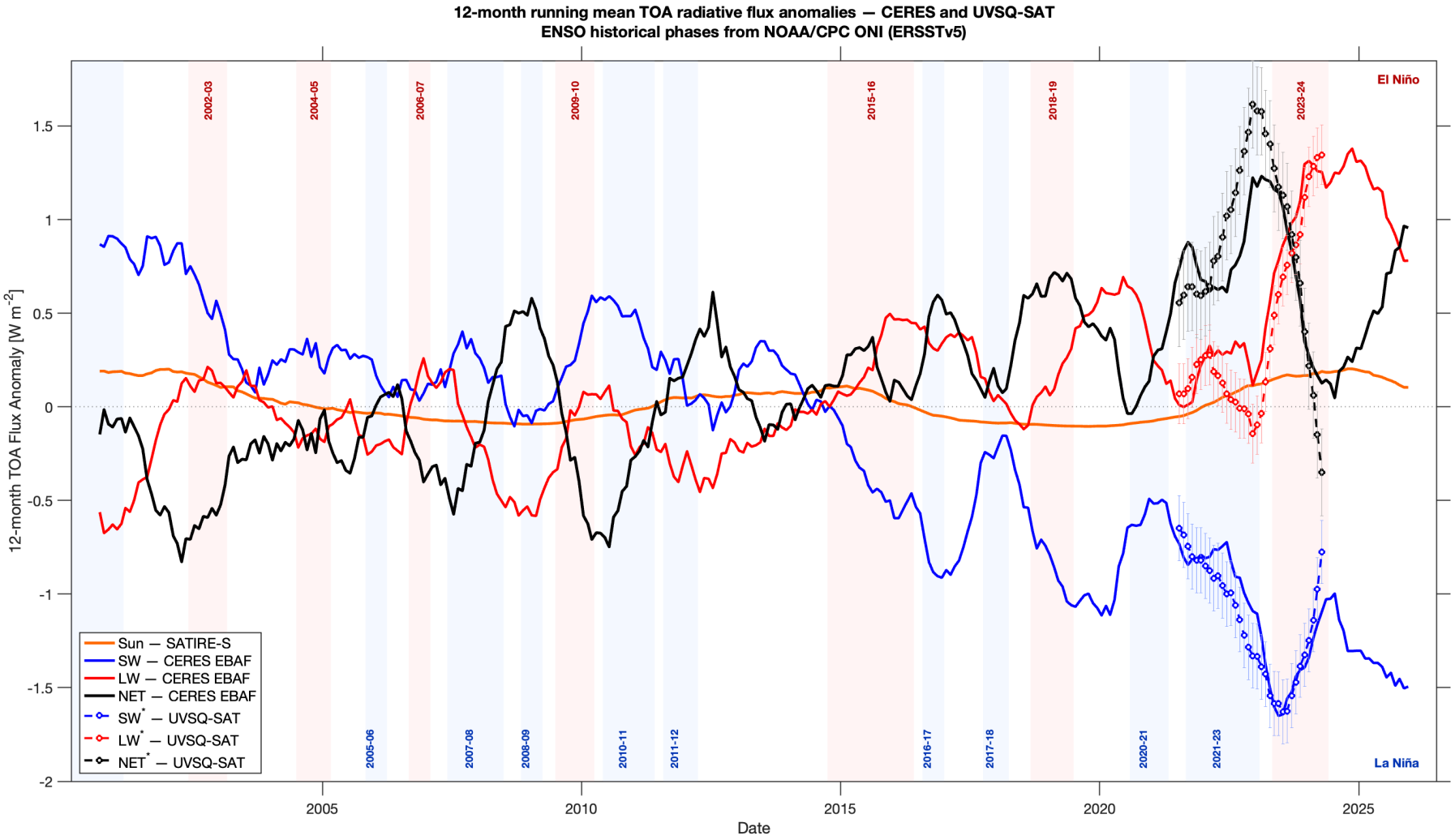






04

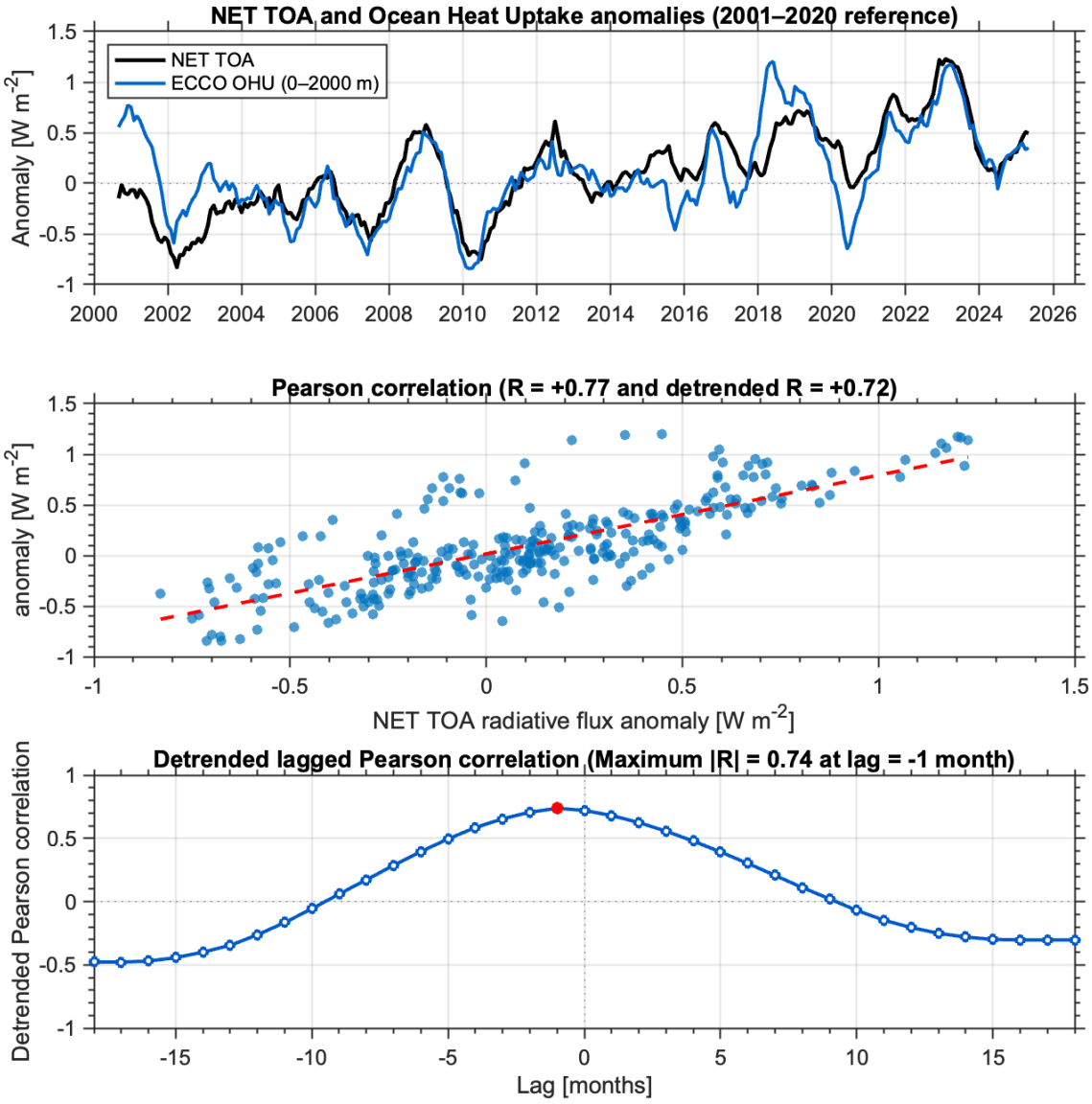
Results, Methods & Limits



ENSO modulates Earth's radiative imbalance, but the long-term increase in NET cannot be attributed to ENSO alone.

04

Results, Methods & Limits



05

Perspectives

❑ Short/long-term ERB–GHG science · constellation

SHORT-TERM / PROCESS

Diurnal OSR/OLR · clouds/aerosols · CO_2 transport · CH_4 events · surface–atmosphere coupling · ENSO / seasonal variability and forcing–response lags

LONG-TERM / CLIMATE

EEI trend · albedo evolution · OLR response · **GHG trends** · feedbacks · **ocean heat uptake** and climate attribution

LONG-TERM DESIGN DRIVER

For CO_2/CH_4 plume monitoring, high spatial resolution implies a narrow instantaneous FOV.

Cross-track scanning increases effective swath and reduces constellation size.

Sampling/revisit dominates

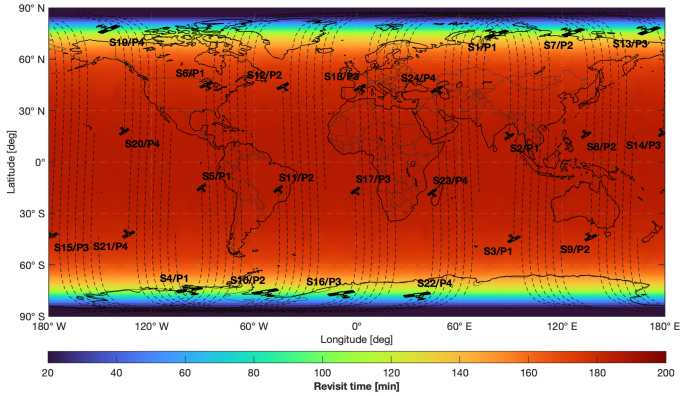
Stability/continuity dominates

Narrow FOV 0.30° full FOV → ~3.1 km swath → ~5,100 satellites for ~3 h global revisit

±15° scan ~320 km swath → 24 satellites slightly >3 h; 36 satellites <3 h

Uvsq-Sat NG validates the ERB–GHG measurement chain; scanning constellations enable high-revisit process observations while supporting long-term climate continuity.

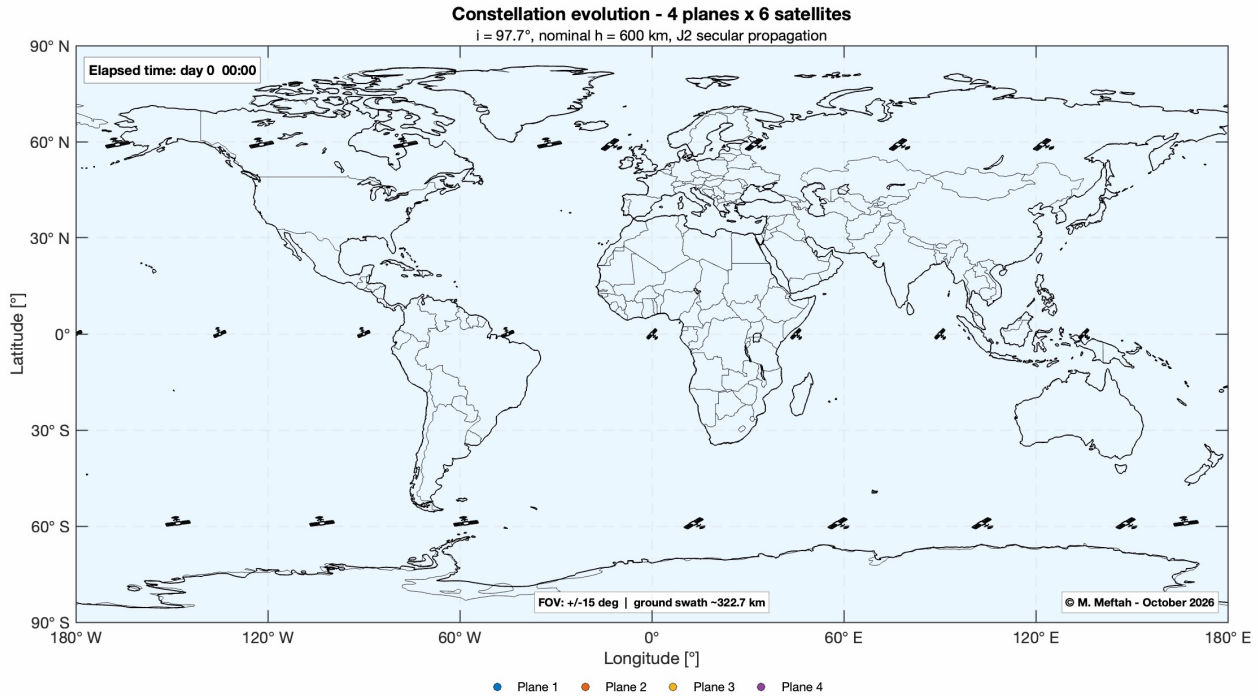
Reference constellation simulation

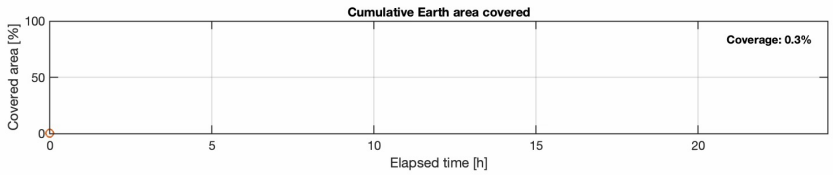


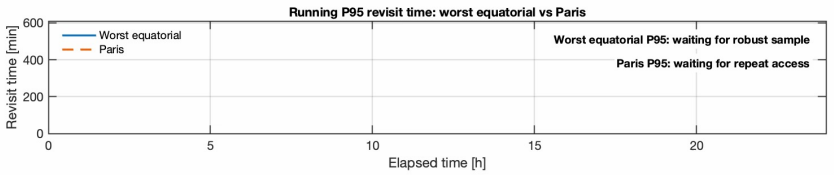
24 satellites (4p6s), 1197 km, i = 87.9°, ±15° half-angle FOV.

05

Perspectives







A hybrid observing architecture combining reference radiometers, cross-calibrated small satellites (e.g. Babar payload), spectral measurements, and heat-storage constraints can improve temporal sampling while preserving climate continuity.

06

Conclusions & Perspectives

SCIENTIFIC QUESTIONS | Q1–Q7

Earth’s Energy Imbalance & ENSO Radiative Signatures

What is established, what we observe with CERES and Uvsq-Sat, and what still needs a physical explanation

01 Energy imbalance & CERES–ERA5 consistency · Q1–Q2

OUR FINDINGS

EEI trend: +0.451 ± 0.196 W m^{-2} $decade^{-1}$ (2001–2025); mean 2021–2025: 0.87 ± 0.23 W m^{-2}.

PHYSICAL CONTEXT

OLR, reflected SW, clouds, aerosols and warming all contribute; reanalysis radiation is model constrained.

TO INVESTIGATE

Partition drivers; quantify absolute biases, trends and interannual differences with matched conventions.

02 Regional signatures, compensation & recurrence · Q3–Q4–Q6

OUR FINDINGS

El Niño: Niño-4 OLR ↓ / OSR ↑ in 7/7 events; Niño-3.4 in 6/7; eastern Pacific less consistent.

PHYSICAL CONTEXT

Geographically opposed SW/LW anomalies can cancel in regional NET and in global averages.

TO INVESTIGATE

Test event-level significance, uncertainty and area-weighted regional contributions.

03 Clouds, convection & ENSO phase evolution · Q5–Q7

OUR FINDINGS

Maritime Continent vs central-Pacific contrasts point to strong cloud-associated radiation changes.

PHYSICAL CONTEXT

Convection shifts cloud amount, altitude and optical properties; OLR and OSR respond differently.

TO INVESTIGATE

Attribute cloud, humidity and temperature effects; track onset → peak → decay.

06

Conclusions & Perspectives

SCIENTIFIC QUESTIONS | Q8–Q11

Radiative Timing, Predictability & Future Missions

A radiative lead is not, by itself, evidence of causality or forecast improvement

04 Opposite lead–lag relationships · Q8 & Q10

OUR FINDINGS

Global OSR leads Niño-3.4 by ~3 months ($r = -0.361$; adjusted $p = 0.020$); global NET lags by ~5–7 months.

PHYSICAL CONTEXT

Regional cloud redistribution and differing SW/LW responses could generate these offsets.

TO INVESTIGATE

Decompose lead–lag covariance by region, wavelength, ENSO phase and lag uncertainty.

05 Does radiation improve ENSO prediction? · Q9

OUR FINDINGS

Across 156 expanding-window monthly hindcasts, OSR predictors show no significant forecast-skill gain.

PHYSICAL CONTEXT

SST, subsurface ocean heat, winds and coupled dynamics remain established ENSO predictors.

TO INVESTIGATE

Evaluate incremental skill from radiances with ocean/atmosphere variables using independent hindcasts.

06 New satellites and CubeSat constellations · Q11

OUR FINDINGS

Uvsq-Sat series may complement CERES with targeted, more frequent regional measurements.

PHYSICAL CONTEXT

Better sampling could resolve the evolution and propagation of radiative anomalies.

TO INVESTIGATE

Demonstrate benefits against calibration stability, uncertainty, sampling and continuity requirements.

06

Conclusions

1 · End-to-end mission

Uvsq-Sat NG was managed entirely in-house: from securing funding and defining requirements to design, launch, operations, and data exploitation.

2 · Education & capacity

A real mission used to train students and engineers across design, AIT, operations, calibration and scientific data analysis.

3 · Test-driven approach

Fast development with early IV&T, mission assurance, reuse of spares, and repeated ground / in-orbit tests.

4 · Scientific results

ERB and imaging exploitation are mature; Uvsq-Sat NG ERB results are being prepared for publication.

5 · Next step

Scanning, cross-calibrated constellations; ≤1 nm spectral resolution; sufficient nadir sensitivity/dynamic range.

Future extension **A dedicated instrument to observe the Earth radiation budget from the Moon is scheduled to fly with Chang'e-7 in 2027.**

Uvsq-Sat NG validates a compact ERB measurement chain, strengthens education through real missions, and prepares the transition toward distributed observing systems.

Thank you