Operational products and Cal/Val for the Copernicus anthropogenic CO2 Monitoring (CO2M) mission

CEOS AC-VC 19
17 October 2023

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CO2M Space Segment

CO2M-A: CO2M Spacecraft CO2M-B: CO2M Spacecraft CO2M-C: CO2M Spacecraft (TBC)

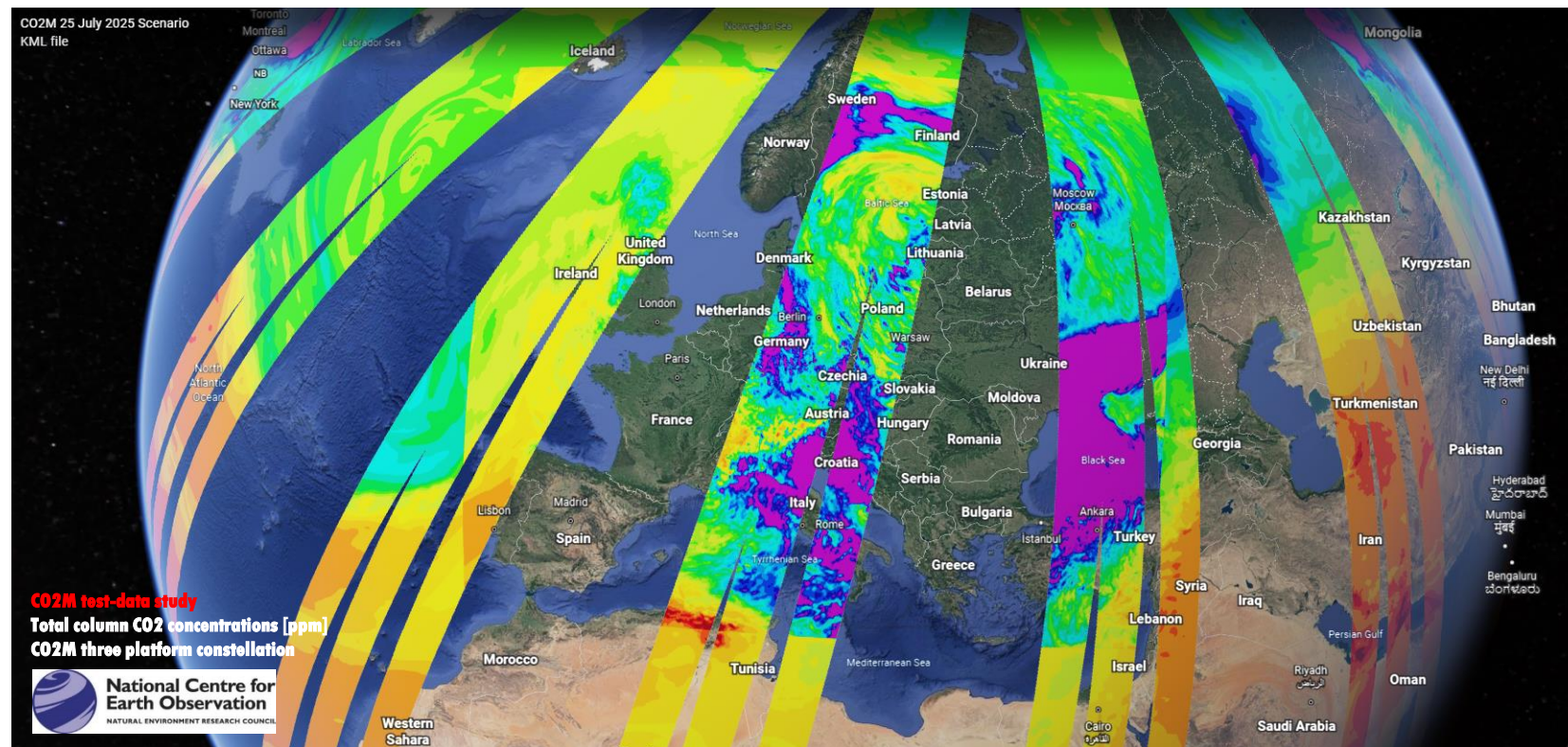**Up to three satellite missions each with >250 km swath:**

✓ Providing greenhouse-gas data for the UNFCCC 2nd global stocktake (GST) in 2028

Three instruments per platform:

- CO_2/NO_2 push-broom grating spectrometer (CO2I/NO2I)
- Multi-Angle Polarimeter (MAP)
- Cloud Imager (CLIM)

Orbit:

- Sun-synchronous orbit 14 5/11
- 159 orbits repeat cycle (~ 11 days)
- 735 km altitude
- 11:30 LT
- Platforms in same orbital plane

CO2M 25 July 2025 Scenario
KML file

CO2M test-data study
Total column CO2 concentrations [ppm]
CO2M three platform constellation

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

Product	Spatial resolution	Precision	Bias
CO2	4 km²	0.7 ppm	<0.5 ppm
CH4	4 km²	10 ppb	<5 ppb
NO2	4 km²	1.5×10^{15} molec/cm²	$<3.5 \times 10^{15}$ molec/cm²
SIF*	4 km²	0.7 mW m⁻² sr⁻¹ nm⁻¹	<0.2 mW m⁻² sr⁻¹ nm⁻¹
Aerosols	6 km²	0.05 AOD, 500 m LH	<0.05 AOD, 500 m LH
Clouds	4 km²	<1% of FOV	

2nd GST

CO2-Monitoring Verification Support capacity
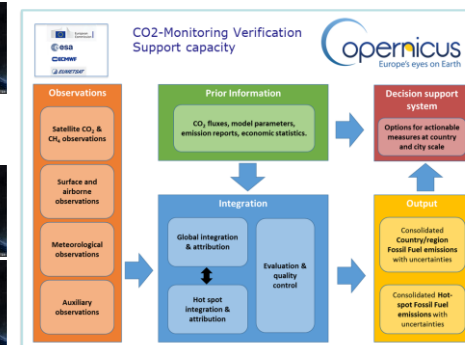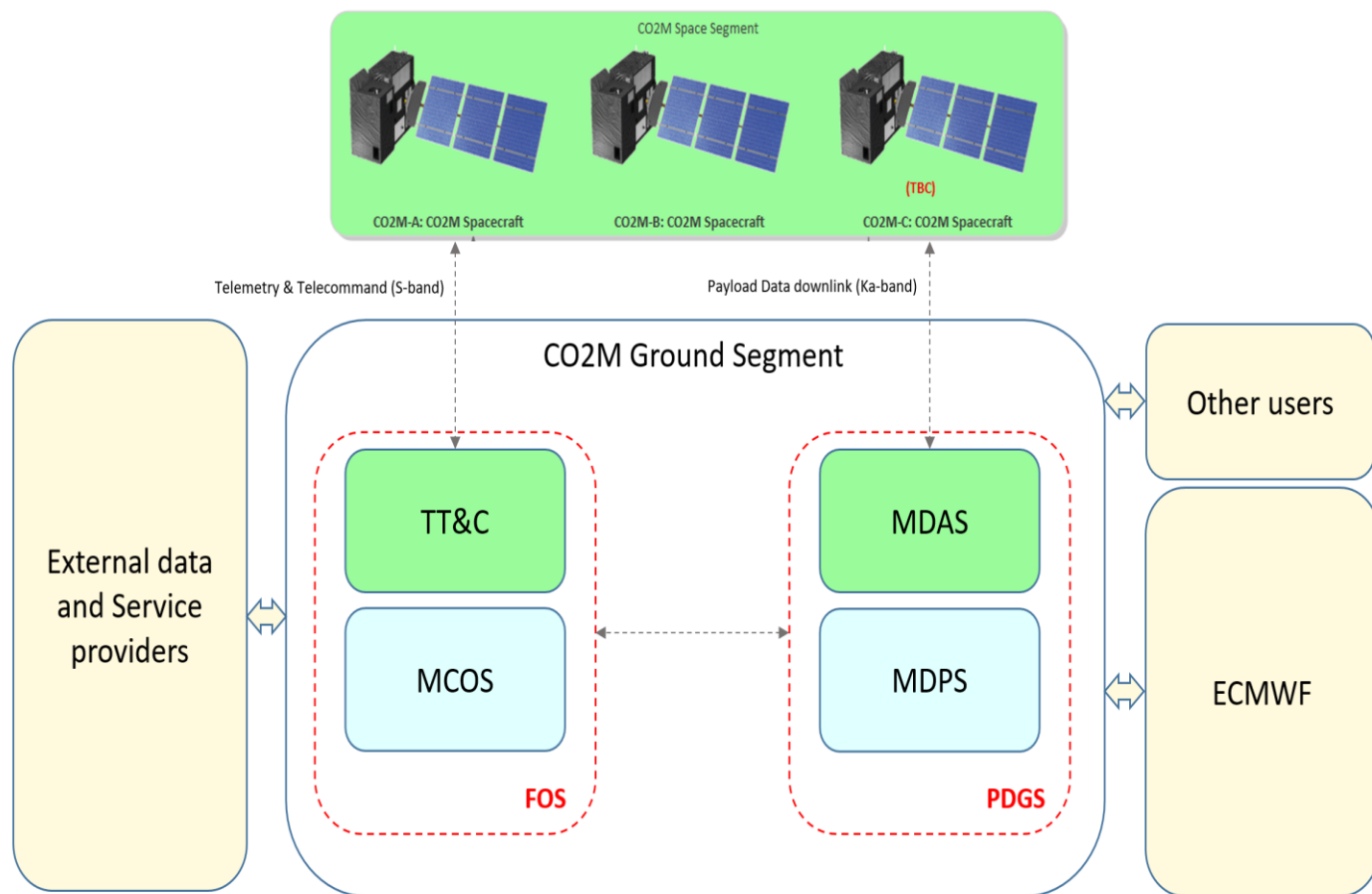
ESA is responsible of the Space Segment development and its commissioning

EUMETSAT is responsible of the development of the operational ground segment (with contributions from ESA) and the CO2M system operations in system commissioning and routine phase.

For payload data (PDGS):

- **MDPS (Mission Data Processing Sub-Segment, including: L0/L/L2 Operational Processors; Archival Dissemination) provided by EUMETSAT;**

- **MDAS (Mission Data Acquisition Sub-Segment) provided by ESA as a service.**

For Flight Operations (FOS):

- **MCOS (Mission Control and Operations sub-segment, including Mission Planning Facility) provided by EUMETSAT;**

- **TT&C (Telemetry, Tracking and Command) provided by ESA as a service.**
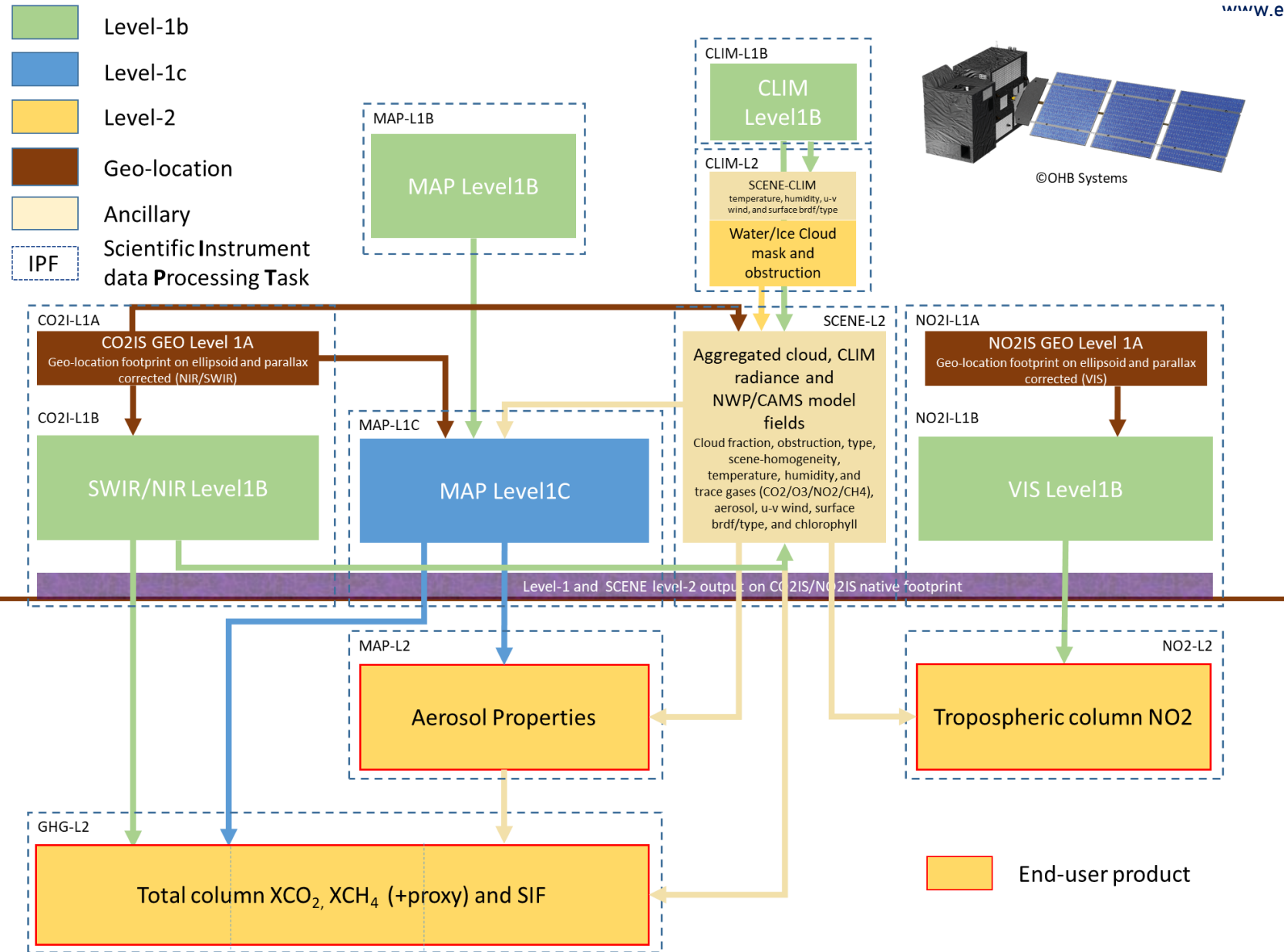
CO2I/NO2I observation statistics

Estimated amount of data (per dayside orbit, per satellite):

Number of measurements (CO2I/NO2I):	~1.1 million
Number of clear sky GHG retrievals:	~200.000
Level-1 / Level-2 GHG/NO2 product sizes:	~35 / 5 GB
All CO2M products:	~280 GB

Estimated number of possible XCO2/XCH4 L2 retrievals:

**Worst case (max land) Scenario**

Orbit type	Worst case (max land) Scenario	Number of observations with surface albedo > 0.03	20 % of total (land/water) used for GHG retrieval due to cloud (<1%) and AOD<0.5
Nadir	Land	630105	131215
	Water (glint>0.03 albedo)	25971	
Pitched	Land	722035	201586
	Water (glint>0.03 albedo)	285895	

**Average (full day) Scenario**

Orbit type	Average (full day) Scenario *)	Number of observations with surface albedo > 0.03	20 % of total (land/water) used for GHG retrieval due to cloud (<1%) and AOD<0.5
Nadir	Land	250530	98065
	Water (glint>0.03 albedo)	249827	
Pitched	Land	239793	200222
	Water (glint>0.03 albedo)	720592	

These figures are per Satellite per orbit.

"Nadir orbit" configuration

Surface Reflectance [1/sr] at 1635.25 nm
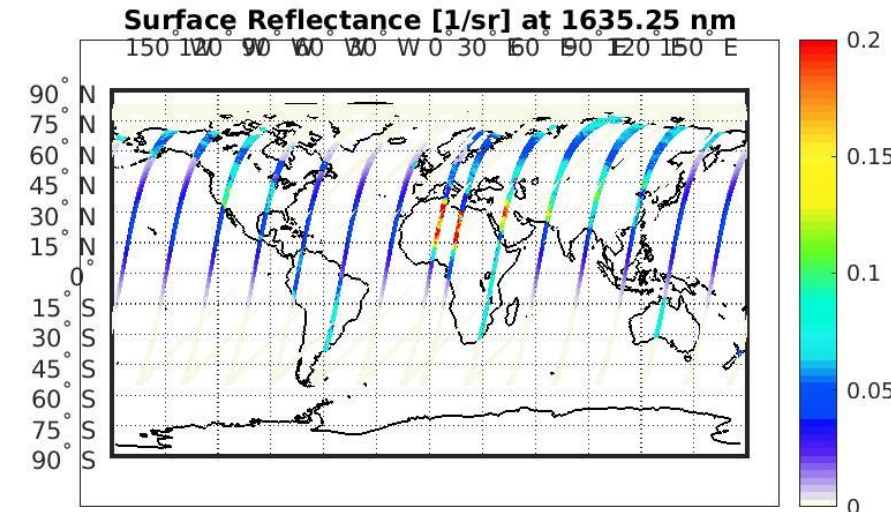
"Pitched orbit" configuration

Surface Reflectance [1/sr] at 1635.25 nm
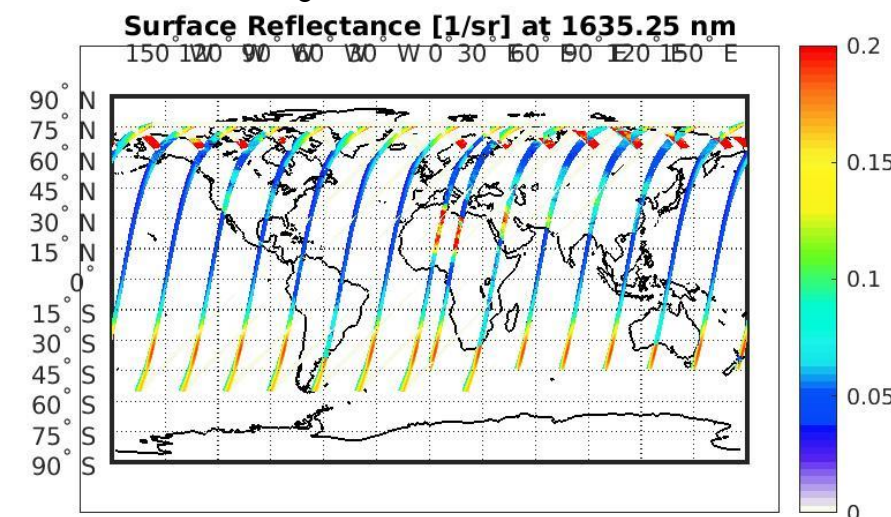
Complementarity, resilience and performance:

- ✓ Different physical retrieval approaches - Full-physics (RemoTAP/FUSIONAL-P), scattering approximation (FOCAL);

- ✓ Different heritage lines (SCIAMACHY, OCO-2, GOSAT, Sentinel5p/5, 3MI, SPEXOne, POLDER);

- ✓ Complementary exploitation of information content of CO2M payload information (CO2I/MAP/CLIM);

- ✓ Complementary processing cost (cheap, medium, heavy).

CO2M platform information content usage:

Processing step	GHG L2 Input		
	RemoTAP	UoL-FP-FUSIONAL-P	FOCAL
Pre	SCENE-L2	SCENE-L2	SCENE-L2
Main	CO2I L1B+MAP-L1C	CO2I L1B+MAP-L2	CO2I L1B
Post			MAP-L1C/L2+CLIM L2

Prelim. processing cost estimates:

GHG L2 :
(3 algorithms)
< 3700 cpus / platform*)

Full system processing:
(including all instruments level-1 and 2)
< 4200 cpus / platform*)

*) Multiple platforms will require less per platform on average because of cpu re-usage

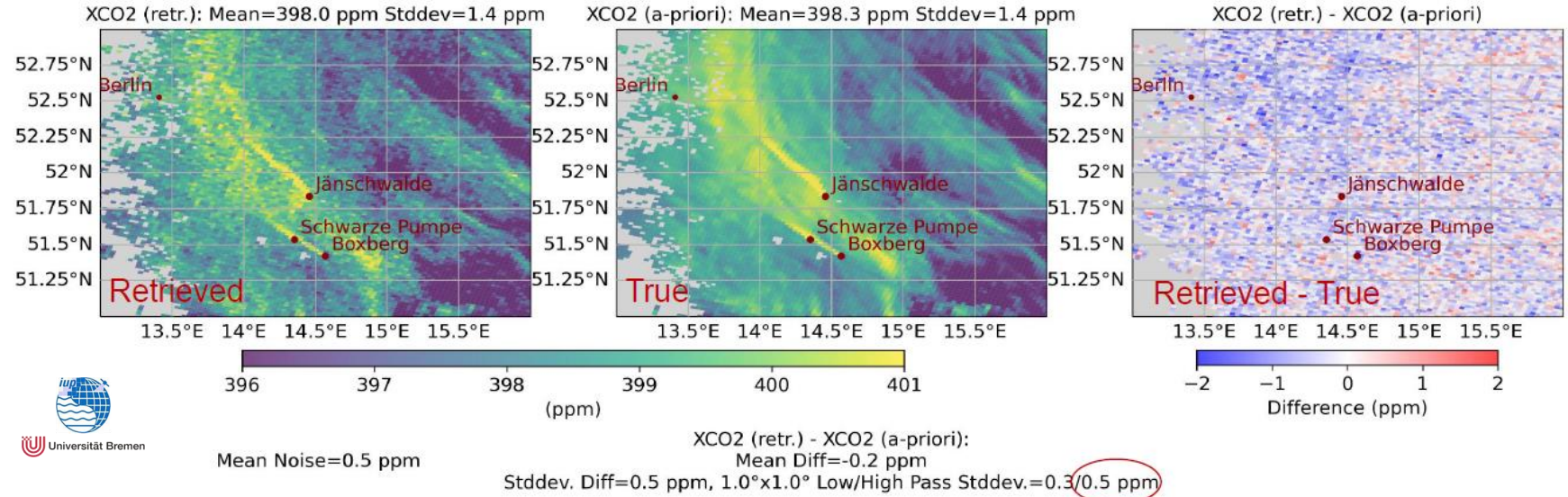www.eumetsat.int

EUMETSAT CO2M GHG science study:

*Three **GHG** algorithms for CO2M*

FOCAL

FUSIONAL-P

RemoTAP

On-board Cal:

Source	CO2I	MAP	CLIM	Frequency
SUN	X	X		daily
Moon	X	X	X	Irreg.
WLS	X			weekly
Tuneable LED	X (ISRF)			
Dark	X	X	X	orbit

GSICS

Vicarious Cal "as needed"

CO2M
0.3 nm (@1.6 µm)

- SNOs
- Ref. Targets
- etc.

Cross-Cal

GSICS

CO2M Calibration and Validation Plan

CO2M product Cal/Val plan

MicroCarb, OCO-x, GOSAT-x, S5, etc.
~0.05 nm (@1.6 µm)

Product VAL

Product Cal/Val

Product Cal/Val

Product Cal/Val

CO2M Ground-Based Network Reference Product Performance Requirements

Ground-based network reference product requirements

Cross-Cal

Cross-Cal

Spectrally oversampled reference

Similar spectral resolution

PANDONIA
5 nm (@1.6 µm)

COCCON
0.14 nm (@1.6 µm)

TCCON
0.001 nm (@1.6 µm)

"Four-pillar" CO2M operational product validation and monitoring space-to-ground and space-to-space approach

+ NDACC/Aeronet for NO_2 and AOD

"Four+-pillar" CO2M validation

GSICS

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GSICS

CO2M product Cal/Val plan

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Product VAL

Product Cal/Val

Product Cal/Val
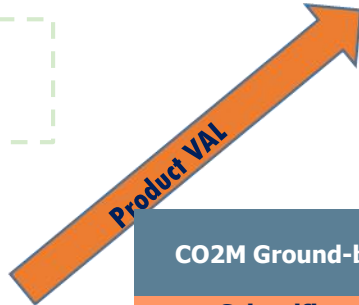
CO2M Ground-based network products central processing hub (ITT: Q 2024)

Scientific support study on ground-based product requirments (LMU)

Scientific support study on ground-based network product processing (KIT)

Spectrally oversampled reference

Ground-based network reference product requirements

Cross-Cal

Cross-Cal

Similar spectral resolution

PANDONIA
5 nm (@1.6 μm)

COCCON
0.14 nm (@1.6 μm)

TCCON
0.001 nm (@1.6 μm)

Scientific feasibility study for PaNIR

"Four-pillar" CO2M operational product validation and monitoring space-to-ground and space-to-space approach

+ NDACC/Aeronet for NO$_2$ and AOD

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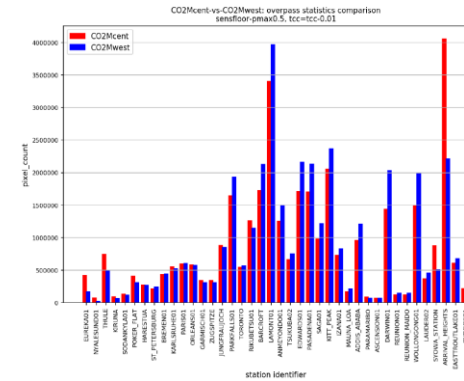## EUMETSAT CO2M Cal/Val study:

Started 1st July 2021

Support definition and metric of product validation (in particular the use of ground-based network product data TCCON, COCCON, NDACC, PaNIR, AirCore, …) for CO2M *operational* monitoring of *anthropogenic* emissions.

➢ *Operational provision of network data (timeliness and availability!)*

➢ *Overpass statistics, station environment and co-location criteria for use of ground-based total column measurements of XCO2, XCH4, NO2 and aerosol close to the sources*

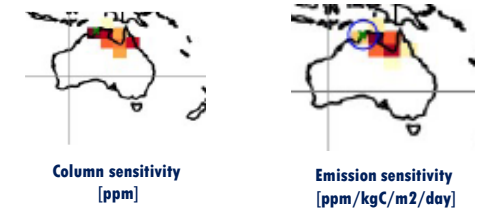➢ *Contributing requirements to ground based network products defined for CO2M*

Database: http://co2m.aeronomie.be

CO2M ground-station overpass statistics:

CO2Mcent-vs-CO2Mwest: overpass statistics comparison
sensfloor-pmax0.5, tcc=tcc-0.01

Station footprint simulation:

Column sensitivity [ppm]

Emission sensitivity [ppm/kgC/m2/day]

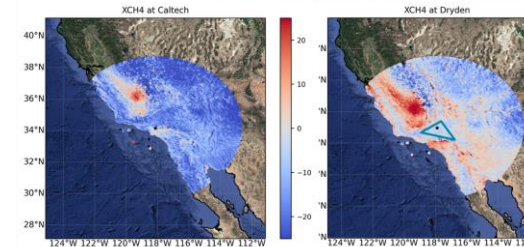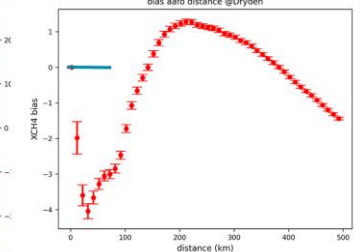*iLab Kaminski et al., EUM CalVal study*

CO2M ground-station co-location criteria:

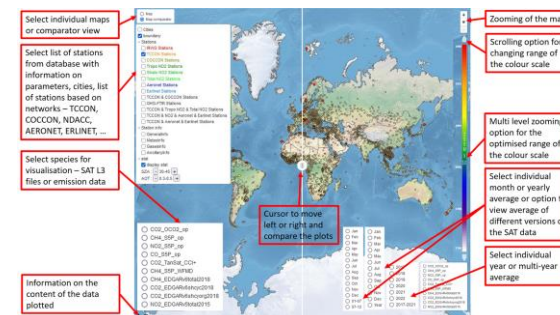Dryden/Edwards XCH4 bias w.r.t TCCON sites
San Joaquin valley (dairy farms)

Dils et al, BIRA, EUM CalVal study

bias aafo distance @Dryden

Over 10 ppb bias >90 km

CO2M validation resource and network-design:

Sha et al, BIRA, EUM CalVal study

EUM Cal/Val Study

iLab

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EUMETSAT CO2M ground-based network product study:

www.eumetsat.int

Started: 1st August 2023 (Karlsruhe Institute for Technology)

Support definition of ground-based network data product processing dedicated to the need of operational CO2M continuous validation and monitoring

➢ *Define ground-based network product (GBP) processing for CO2M: complement existing network products (level-2) with CO2M tailored network products (CO2M-GBP L2)*

  ➢ Processing of CO2M tailored products (CO2M-GBP L2) (e.g. from TCCON, COCCON, …)

  ➢ Reduced spectral resolution (increase SNR), use of common auxiliary information (a priori model data, cross-sections, etc.) as used by CO2M GHG processors, etc.

  ➢ Evaluate/monitor/trace network to network and station to station biases (TBC)

  ➢ Compare performance of CO2M-GBP L2 to network standard products (NS-GBP L2)

  ➢ Make network provided and CO2M tailored products available to CO2M validation and continuous monitoring

  ➢ Make input (auxiliary data, cross sections etc) fused in CO2M tailored products available to ground-based network product producers

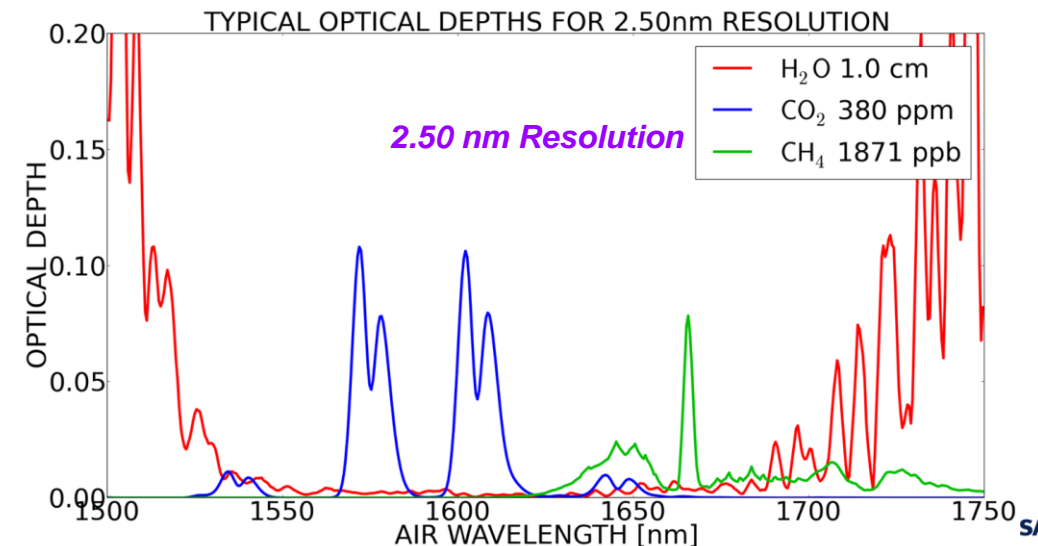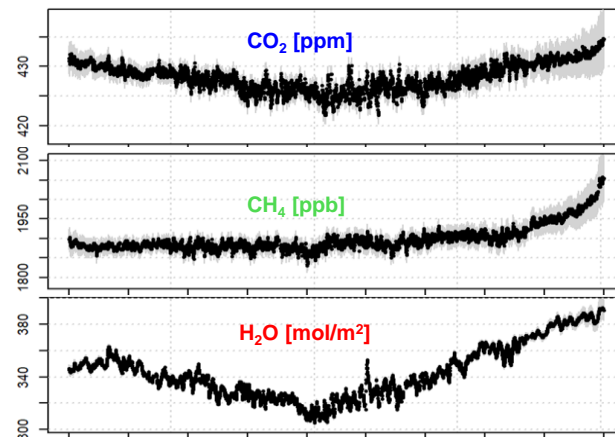➢ *Support engineering of operational ground-based network data processing system*

www.eumetsat.int

- Modified Pandora-2S with NIR & Visible channel for columnar measurements of CO_2, CH_4 and H_2O

- Wider resolution (compared to FTIR) allows:
  - High frequency direct sun measurements
  - Sky observations to retrieve information on the spatial inhomogeneity and vertical distribution of the GHG

- Developed for producing real time data

- Low acquisition and operation costs
  - No problems during unattended operations at Innsbruck (Nov 2022 to Mar 2023) and Izaña (Mar 2023 to present)

Spec 2   Spec 1

Sun & Sky Viewing

EUM CO2M study with:

LUFTBLICK
EARTH OBSERVATION TECHNOLOGIES
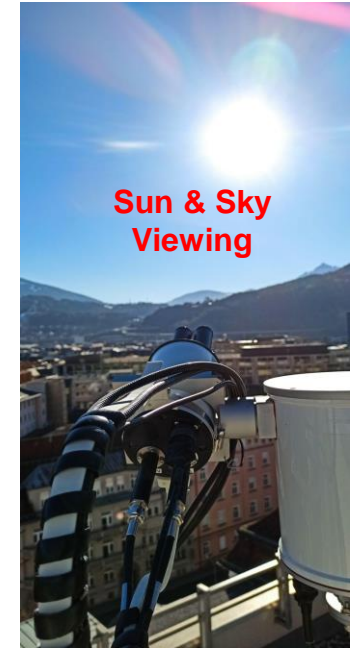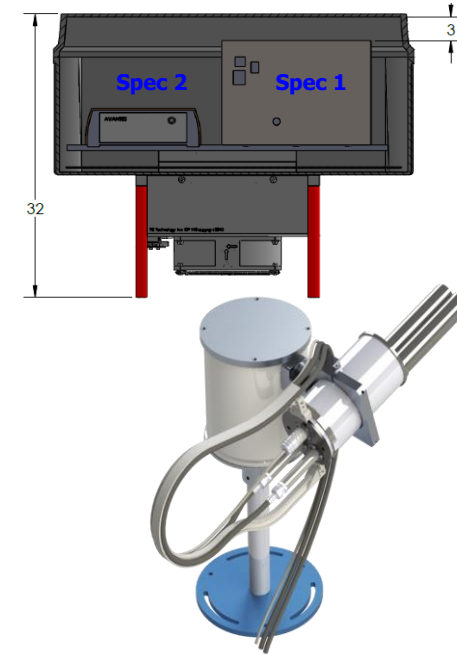
High frequency (every second) direct sun dry air mole fractions on 30 Mar 2023 at Izaña from Pandora 234 ("PaNIR")

CO_2 [ppm]

CH_4 [ppb]

H_2O [mol/m²]

TYPICAL OPTICAL DEPTHS FOR 2.50nm RESOLUTION

2.50 nm Resolution

— H_2O 1.0 cm
— CO_2 380 ppm
— CH_4 1871 ppb

OPTICAL DEPTH

AIR WAVELENGTH [nm]

- **CO2M Cal/Val plan version** available (version 2 due by System CDR);

- **EUMETSAT** is developing a dedicated document for **ground-based (network) product requirements** for future CO2M product validation and continuous monitoring;

- **EUMETSAT** is developing a **dedicated facility for provision and central processing of ground-based network data** for CO2M product validation and monitoring;

- **EUMETSAT** is working with the ground-based networks (TCCON, COCCON, NDACC, Pandonia, Aeronet) on the central routine provision of level-1 data for CO2M operations.
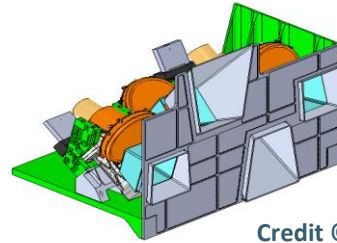
Thank you!

Questions welcome.

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CO2M INSTRUMENTS

CO2I/NO2I push-broom grating spectrometer

- **Target species:** **CO2, CH4 & NO2**
- **Spatial resolution:** **4 km²**

Band	Spectral range	Spectral resolution
VIS	405–490 nm	0.3 nm
NIR	747–773 nm	0.2 nm
SWIR-1	1590–1675 nm	0.3 nm
SWIR-2	1990–2095 nm	0.35 nm

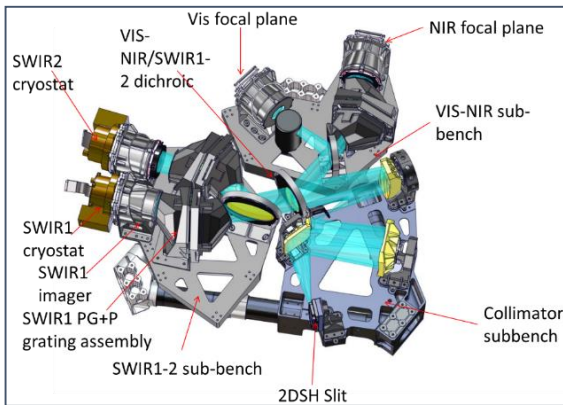**Credit © TAS-France**

Multi-angle polarimeter

- **Target species:** **Aerosol**
- **Spatial resolution** (native)**:** **1 km²**
- **43 views (0 > OZA < 60°)** (out of 48 native)
- **Spatial resolution** (aerosol product)**:** **4 km²**

Credit © TAS-UK

Cloud imager

- **Target species:** **Clouds**
- **Spatial resolution:** **100 / 200 m**

Credit © OIP (Belgium)

See presentation by Gregory Bazalgette Courreges-Lacoste

MAP Band	Wavelength
VNIR-1	410 nm
VNIR-2	443 nm
VNIR-3	490 nm
VNIR-4	555 nm
VNIR-5	670 nm
VNIR-6*	753 nm
VNIR-7	865 nm

* Channel used for cross calibration purposes with less views
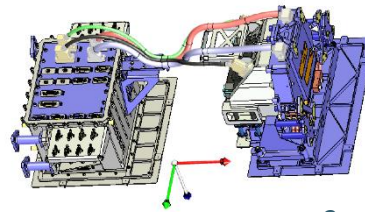
CLIM Band	Wavelength
CLIM-1	670 nm
CLIM-2	753 nm
CLIM-3	1370 nm

CO2M CO2I spectrometer false colour radiance image (VIS/NIR/SWIR)

CO2M 6-orbits test-data set of top-of-atmosphere radiances for a constellation of 3 platforms

"West" platform continuously pointing towards the sun-glint spot

3rd July 2025 (205)
1. EU west (pitch on)
2. EU cent (pitch: off)
3. EU east (pitch: off)

9th Sep 2025 (205)
1. Asia cent (pitch: off)
2. Asia west (pitch: on)
3. Asia east (pitch: off)