Credit: OHB

Anthropogenic Greenhouse Gas Monitoring with the Copernicus CO$_2$ Monitoring (CO2M) Mission

Yasjka Meijer, PhD

European Space Agency (ESA)

CO2M Mission Scientist

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ESA CO2M Project Team
V. Fernandez (project manager), Y. Durand (Payload & CLIM manager), G. Bazalgette Courreges-Lacoste (Payload System & CO2I), C. Pachot (MAP), M. Martinez Fernandez (Satellite & AIV manager), D. Sanchez-Cabezudo (System manager), Y. Meijer (Mission Scientist)

EC, DEFIS, Brussels, Belgium
E. Andersson, H. Zunker

CO_2 Monitoring Mission Advisory Group (MAG), Major international institutions
**H. Boesch, M. Buchwitz, M. Dowell, O. Dubovik, R. Engelen, D. Jouglet, G. Kuhlmann, J. Landgraf, H. Lindqvist, J. Marshall, M. Nakajima, N. Rozemeijer, P. Veefkind**

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Monitoring & Verification Support Capacity
System requirements & impact on satellite requirements

1. **Detection of emitting hot spots** such as megacities or power plants
   → **high precision CO_2 data, high spatial resolution, no local biases**

2. **Monitoring the hot spot emissions**

   to assess reductions or increase in emissions
   → **quantify emissions (plume info), frequent revisit**

3. **Assessing emission changes against local reduction targets**

   to monitor impacts of the Nationally Determined Contributions
   → **no regional biases, separate biogenic from anthropogenic**

4. **Assessing the national emissions and changes**

   in 5-year time steps to estimate the Global Stock Take
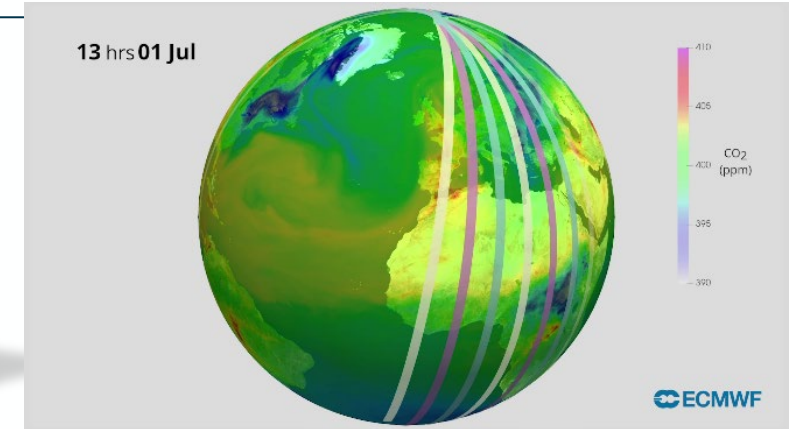   → **no long-term drifts, high accuracy data, inter-calibrated**
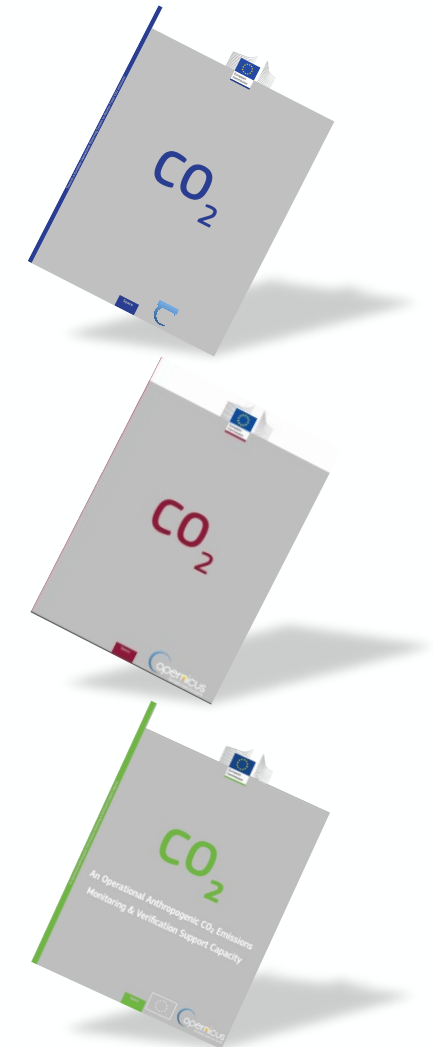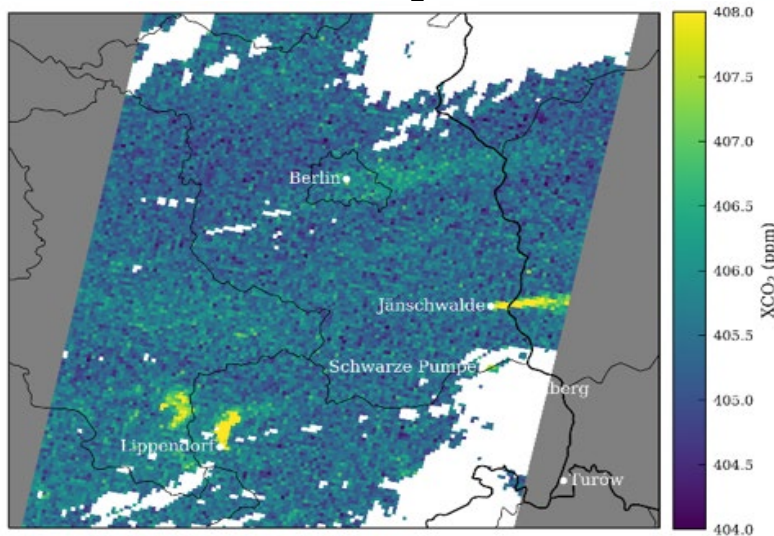
CO2M Mission Requirements 1/4

Mission requirements for CO_2, CH_4 & NO_2:

- Spatial resolution: **4 km²**
- Imaging swath: **> 250 km**
- CO_2 precision: **0.7 ppm**
- CO_2 systematic bias **< 0.5 ppm (0.15% (!))**
- CH_4 precision: **10 ppb**
- NO_2 precision: **$1.5 \cdot 10^{15}$ molec/cm²**
- Viewing modes: **nadir (land) & sun-glint (water & snow)**
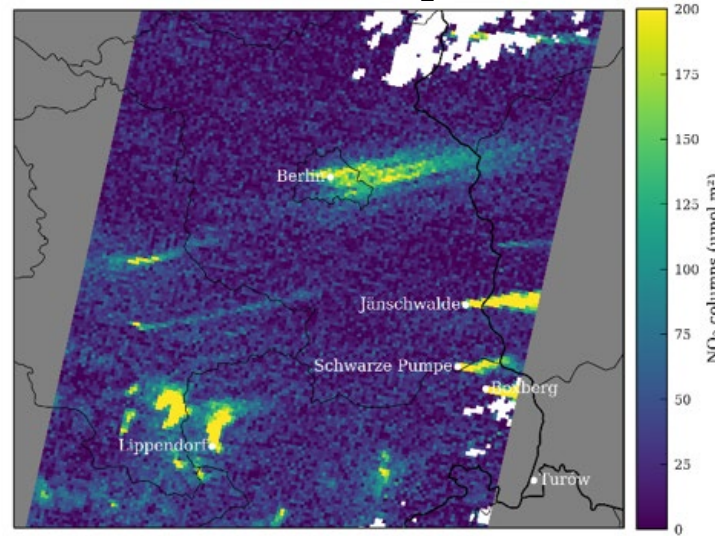
MRD

Credits: EMPA

Simulated CO_2 plumes
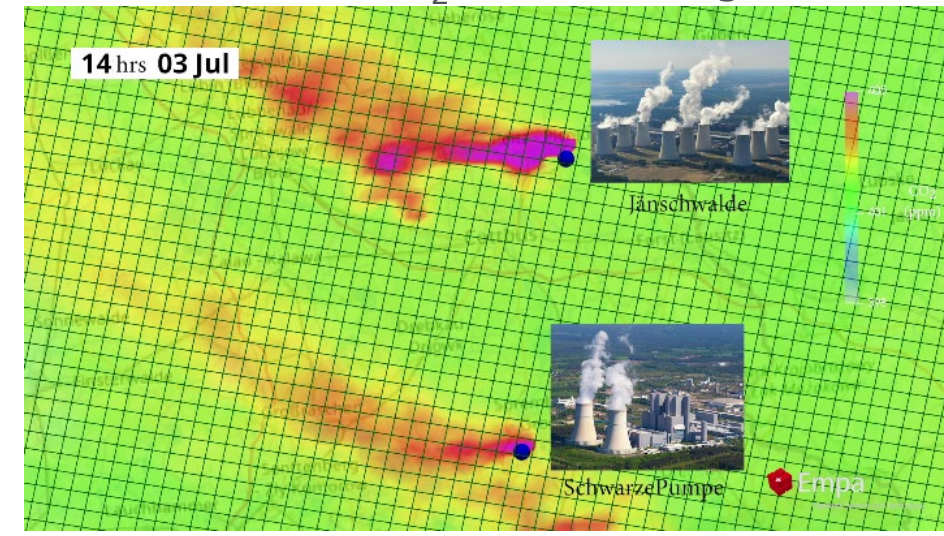

Germany with Berlin and power plants

Credits: EMPA

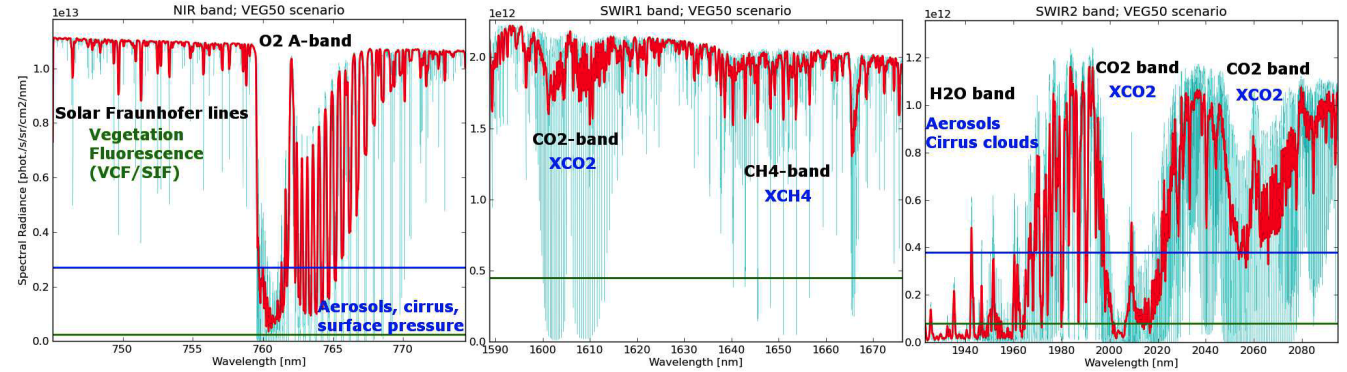Simulated NO_2 plumes

Credits: EMPA

Simulated CO_2 at 2x2 km² grid

Power plants near Berlin, Germany

Credits: EMPA

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CO2M Mission Requirements 2/4

Mission requirements for XCO$_2$ & NO$_2$:

Spatial co-registration:	**95% overlap**
Geolocation knowledge	**300 m**
Absolute radiometric accuracy:	**3%**
ISRF shape knowledge:	**2%**

Band	Spectral range	Spectral resolution	Spectral sampling ratio	SNR$_{ref}$ @ L$_{ref}$ (photons/s/nm/cm^2/sr)
VIS	405–490 nm	0.6 nm	3	750 @ 1.35 x 10^{13}
NIR	747–773 nm	0.12 nm	3	330 @ 6.4 x 10^{12}
SWIR-1	1590–1675 nm	0.3 nm	3	400 @ 2.1 x 10^{12}
SWIR-2	1990–2095 nm	0.35 nm	3	400 @ 1.8 x 10^{12}

Pushbroom imaging spectrometer

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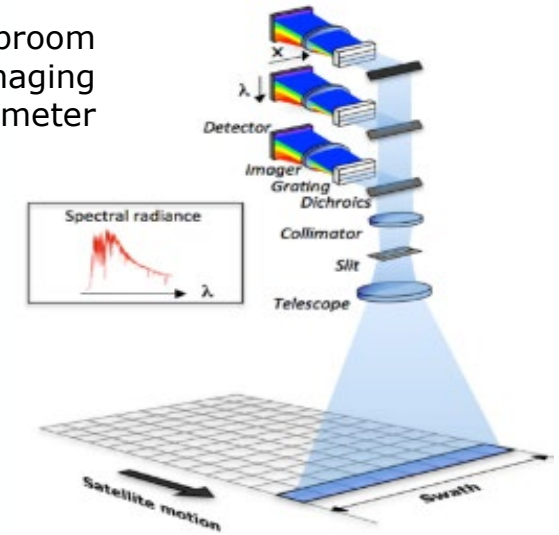
CO2M Mission Requirements 3/4

Aerosol & cloud scattering:

Light path correction is very important and requires aerosol and cloud information
Heritage missions filter for too high aerosol loading (Aerosol Optical Depth, AOD<0.3)
Thin cirrus & small cloud fractions → incompliant to CO_2 error budget

For Copernicus CO2M mission, aerosol measured with a MAP instrument & clouds with an imager:
→ **Higher accuracy CO_2 data (less posterior bias correction)**
→ **More data and also at higher aerosol loading; up to 0.5 AOD**
→ **Cloud cover of CO_2 pixel identified to 1–5%**

Credits: SRON

MODIS AOD, high in India & China
JUN. 2018

Aerosol amount (AOD)

0.0   0.5   1.0
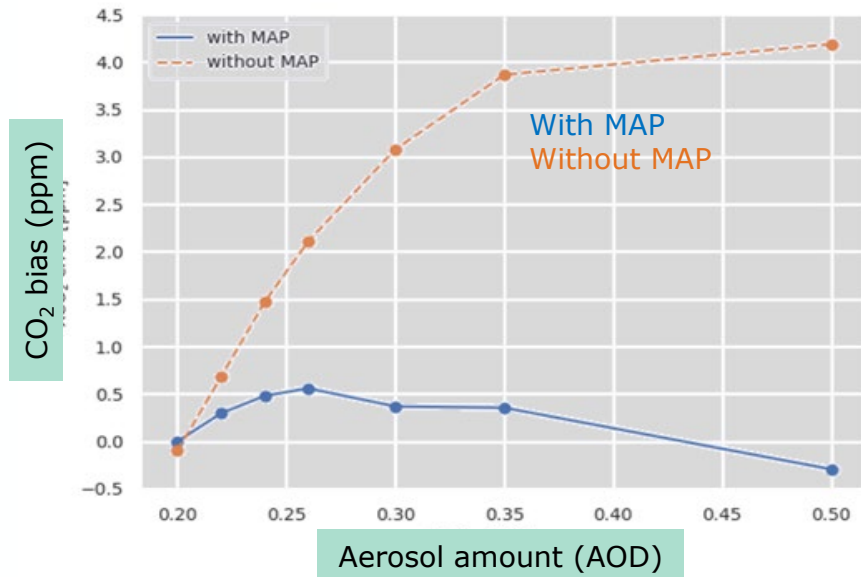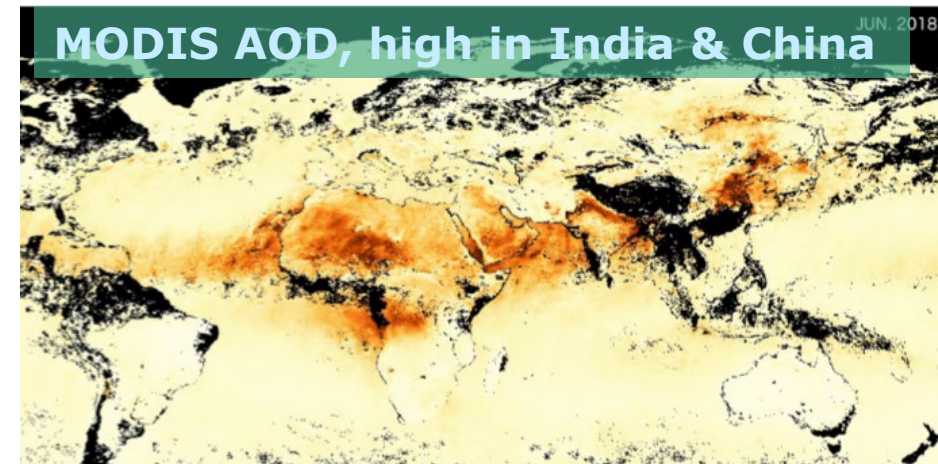
Credits: SRON

CO2M Mission Requirements 4/4

Aerosol data:

- Multi-angle polarimeter (MAP) for light path correction
- 40 views multi-channel
- Observation zenith angle **+/- 60 degrees**
- Spatial resolution **4x4 km^2 @ 4x oversampling**
- Degree of linear polarisation (DoLP) total error **<0.0035**

Cloud Imager (CLIM)

- Multi-channel imager
- Spatial sampling **400 m**

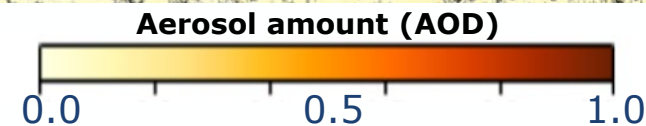| MAP Channel	Central wavelength	Spectral width
VNIR-1	410 nm	20 nm
VNIR-2	443 nm	20 nm
VNIR-3	490 nm	20 nm
VNIR-4	555 nm	20 nm
VNIR-5	670 nm	20 nm
VNIR-6	753 nm	9 nm
VNIR-7	865 nm	40 nm

CLIM Channel	Central wavelength	Spectral width	SNR
CLIM-1	670 nm	20 nm	200
CLIM-2	753 nm	9 nm	200
CLIM-3	1370 nm	15 nm	200

MRD

CO2M Space Segment - key features

Credit: OHB SE

Platform subsystems	All subsystems from well known technology with performance (power, memory, etc..) in the range of existing Copernicus missions
Electrical Power (EPS)	Solar Array: 3 panel wing steered by SADM
AOCS	Gyroless architecture, 3-axis stabilised
Propulsion and Reaction control (RCS)	Mono-propellant, with 8 Thrusters (20N) 2 Tanks sized for controlled re-entry
TT&C Mission Data	S-band TM/TC and ranging Ka-Band single channel (1.8 Gbits)
Data Storage	Mass Memory > 3Tbits (EoL)

Mission architecture

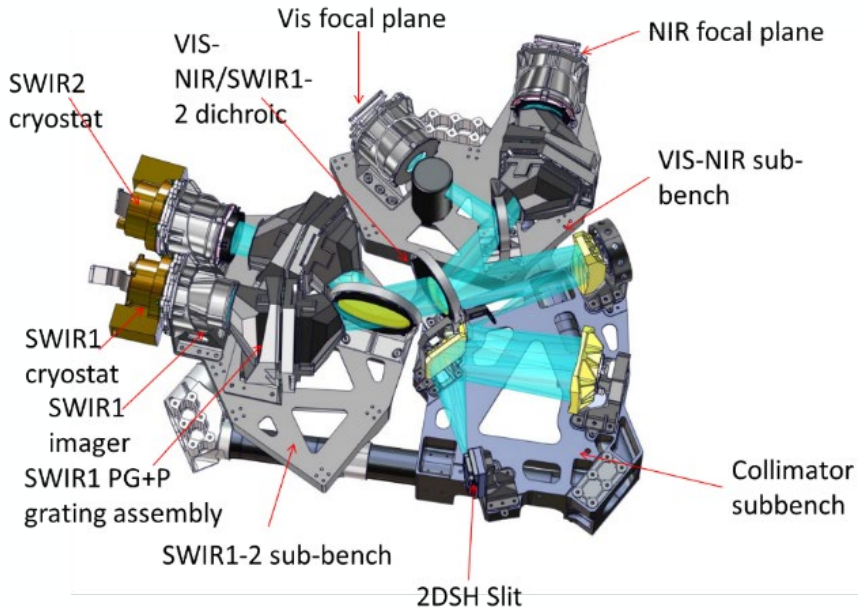|	
Reference Orbit	Reference altitude: 735 km LTDN: 11:30
Repeat cycle	Full coverage after 11 days with 1 satellite improved to 5 days with 2 satellites
Science data latency	Max. latency : 3.3h, based on 1 Ground station
Lifetime	7.5 years Extendable to 12 years (consumable sized accordingly)
Satellite Mass	~1.65 tons
Launcher	Baseline: Vega-C Back-up: Ariane 6

Credit: OHB SE

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CO2M Payload

Push-broom imaging spectrometer

Credit: TAS-F

Labels: SWIR2 cryostat, VIS-NIR/SWIR1-2 dichroic, Vis focal plane, NIR focal plane, VIS-NIR sub-bench, SWIR1 cryostat, SWIR1 imager, SWIR1 PG+P grating assembly, SWIR1-2 sub-bench, 2DSH Slit, Collimator subbench

Credit: QSIL

Credit: IOF

Prism-Grating Prism

Optical Bench Structural Model

Multi-Angle Polarimeter (MAP)

Four identical, simple cameras each 12 views and 7 spectral bands. A TE2V CIS-120 detector, patterned with multi-spectral filter and micropolarizers

Credit: TAS-UK

Labels: Electronics mounting panel, Proximity electronics, Radiator, Camera (1 of 4), External baffle (1 of 4), Flight Calibration Unit (1 of 4)

Credit: TAS-UK
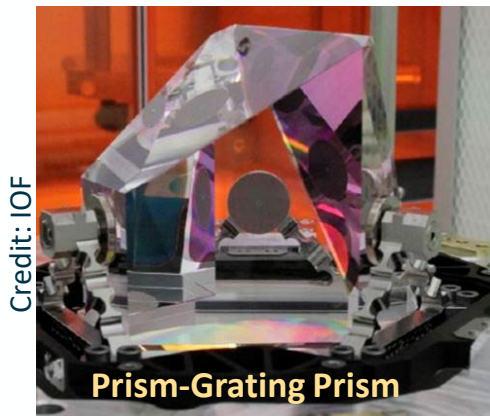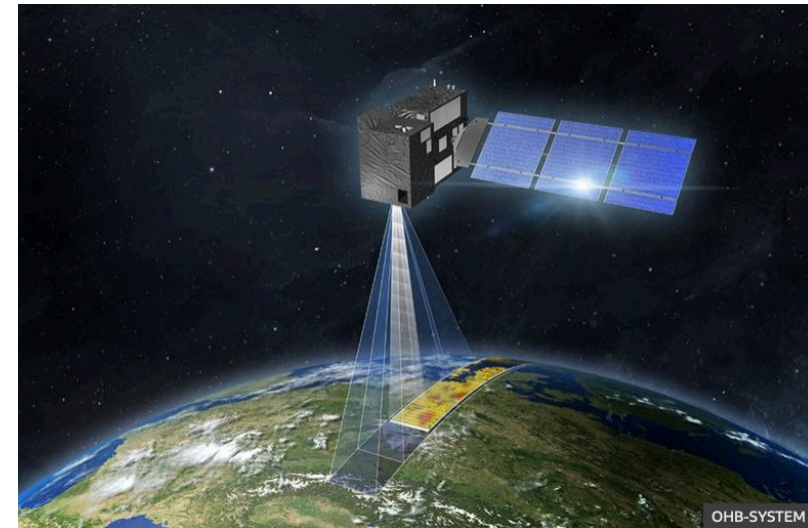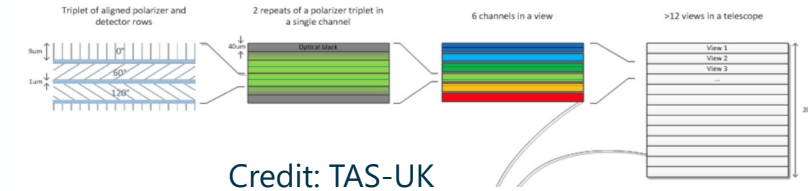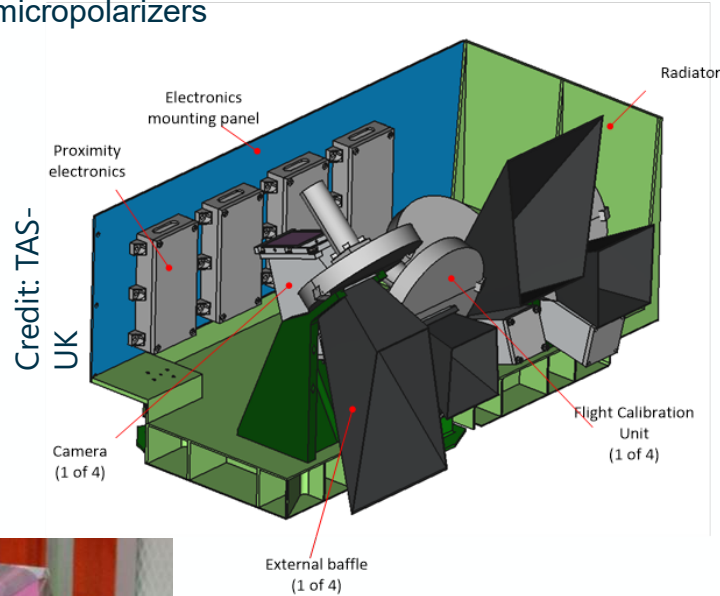
Cloud Imager

Three band (670, 753, 1370 nm) imager based on PROBA-V

OHB-SYSTEM

Credit: OIP

Labels: TMA (within structure), Detector proximity electronics

Science Support Activities 1/2

Study on Improved Glint Retrieval for CO2M – SNOWITE:

Analysis of **wind** for glint signal over water

- Glint is easily observed across the swath (except for the lowest wind speeds)
- Increasing wind speed smoothens the glint signal
- Selecting cloud-free scenes results in (on average) lower wind speeds

Analysis of **snow** for glint signal over land

- Potential increase in data, esp. March-May
- Strong forward reflecting peak suggesting importance of glint mode over snow

Credits: FMI

Snow state: 1 March 2018

Snow-free landscape

Patchy snow cover

Full snow cover

Credits: FMI

Eurasia 5°E-60°E

Credits: FMI

Old_snow

Credits: FMI

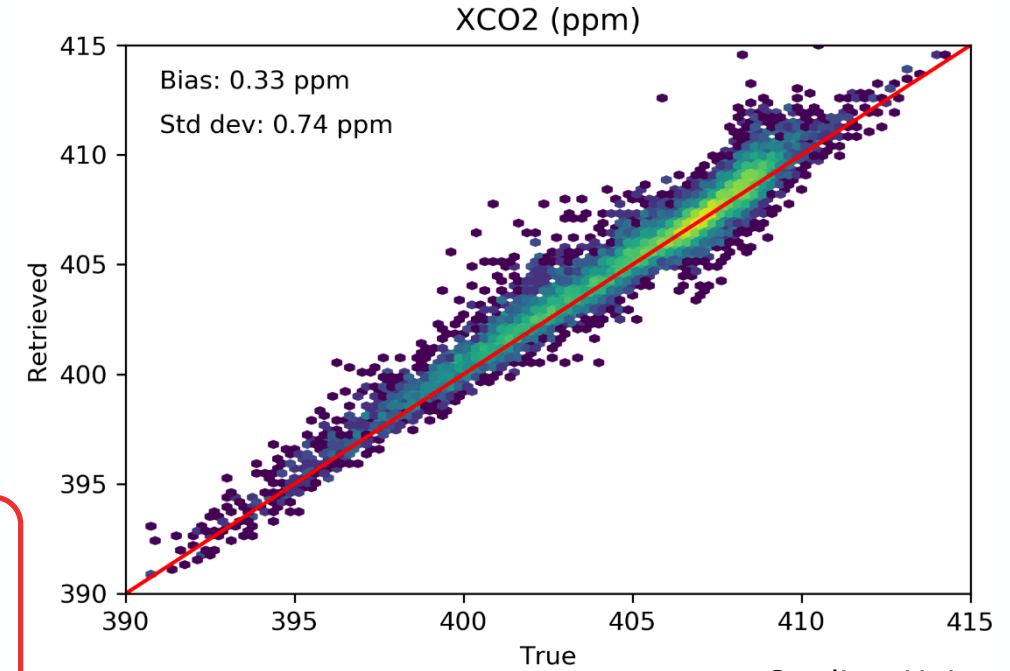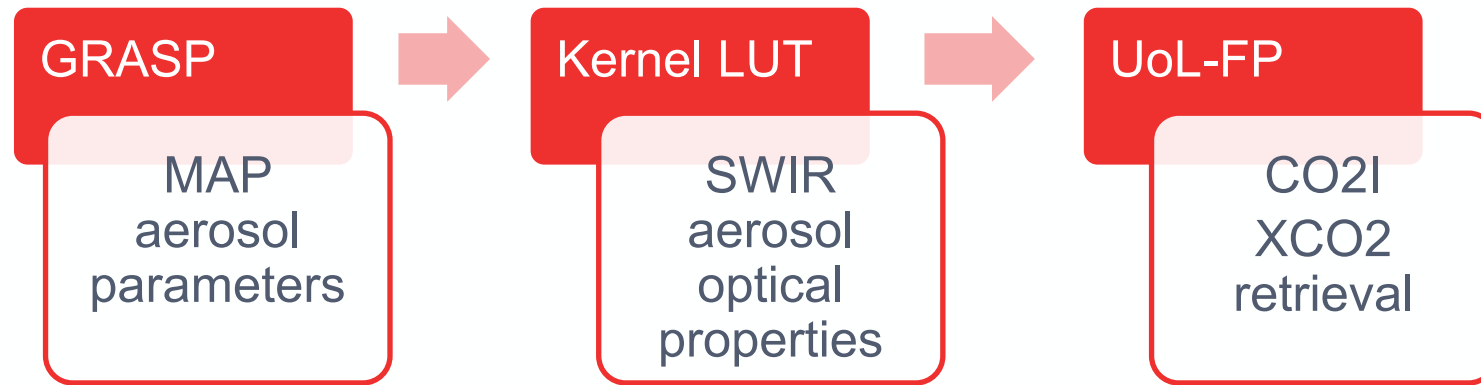| Fraction of OCO-2 observations (above 45 °N)			
Over ocean → water	Over ocean → ice	Over land → no snow	Over land --> snow cover
22,8%	6.9%	48.6%	21,8%

Science Support Activities 2/2

Alternative MAP-based CO_2 Retrieval Algorithm:

- Developed a sequential retrieval exploiting MAP data for UoL CO_2 retrieval algorithm
- Global ensemble of simulated data
- Confirmed the positive impact of using MAP data

GRASP → **Kernel LUT** → **UoL-FP**

MAP aerosol parameters	SWIR aerosol optical properties	CO2I XCO2 retrieval

XCO2 (ppm)

Bias: 0.33 ppm
Std dev: 0.74 ppm

Credits: Uni. of Leicester

Upcoming activities:

- Study on Scientific Support to CO2M Satellite Project
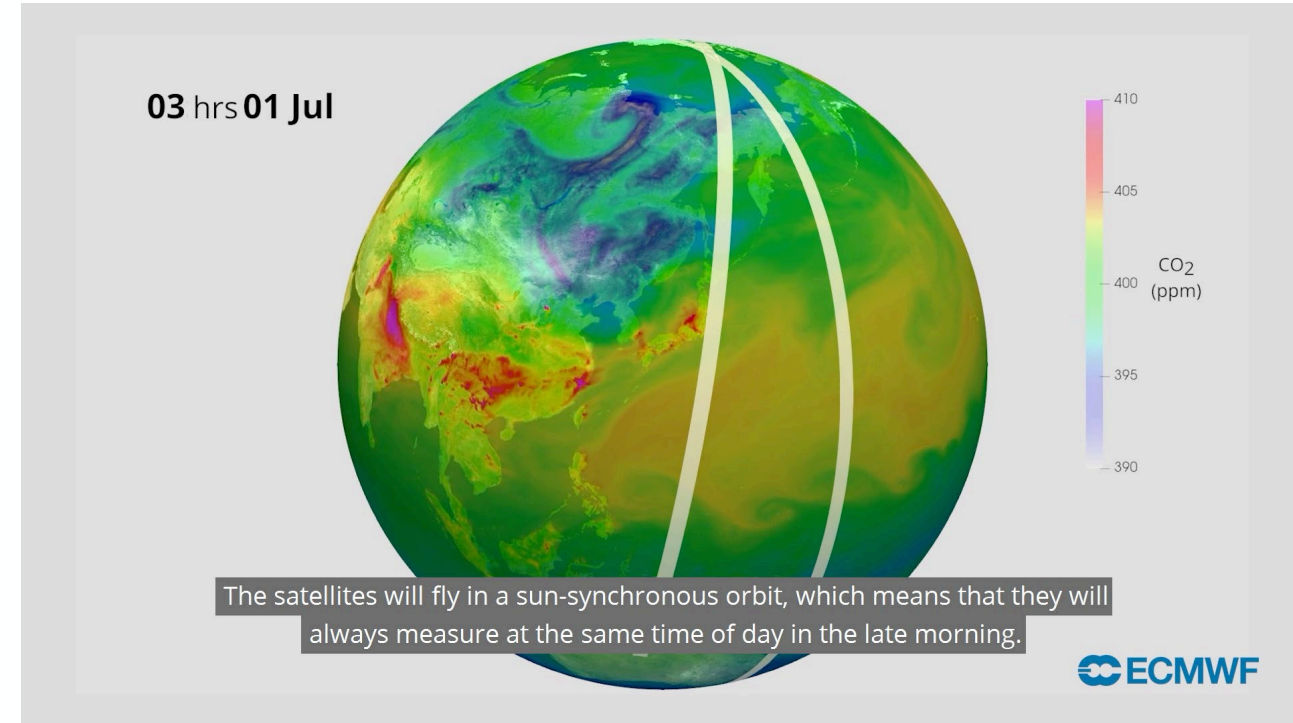- Mission Operational Concept Development Study for CO2M Glint Mode

Copernicus CO2M Mission – Status

Project status:

- Preparatory phases completed in **2014–2019**

- Implementation phase started in **July 2020**

- Implementation **on schedule** with
    - SAT PDR completed in **March 2022**
    - PL PDR on-going

- Full contract including payload prime signed in **May 2022** (here at LPS)

- First & second satellite Flight Acceptance expected end of **October 2025**

- Possible **3rd satellite** pending EC decision

Amount of data (per orbit, per satellite):

Number of measurements:	~1.1 million
Number of clear sky retrievals:	~200,000
Spectra/ CO_2, CH_4 & NO_2 product sizes:	~35 / 5 GB

03 hrs 01 Jul

The satellites will fly in a sun-synchronous orbit, which means that they will always measure at the same time of day in the late morning.

Credits: EMPA

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CONSORTIUM

OHB
MISSION & PLATFORM PRIME

ThalesAlenia Space
a Thales / Leonardo company
PAYLOAD PRIME & E2ES

OHB-SYSTEM

PLATFORM AND SYSTEM SUPPORT

PRESELECTED SUBCONTRACTORS

OHB	
MTA Aerospace	RCS
Omnidea-RTG	
ArianeGroup	
Bradford	
RUAG	
RUAG	AOCS
Zarm	
Rockwell-Collins	
Sodern	
SAFT	
CRISA	EPS &
Kongsberg	HARNESS
SpaceTech	
E.I.S.	
TESAT	DDS
Evercare	SW
Intelligentia	

SYSTEM SUPPORT & TEST FACILITES	Vito / ETS
GSE	Atos / Astos / Spirit / Highftech / AirWorks
TT&C	LuxSpace / RUAG / TAS-E
DHS & PDHS	RUAG / TERMA / Airbus
STRUCTURE & THERMAL	INVENT / OHB / FHP
DAS	RUAG / RUAG

CO2M PAYLOAD, CO2I/NO2I & E2ES
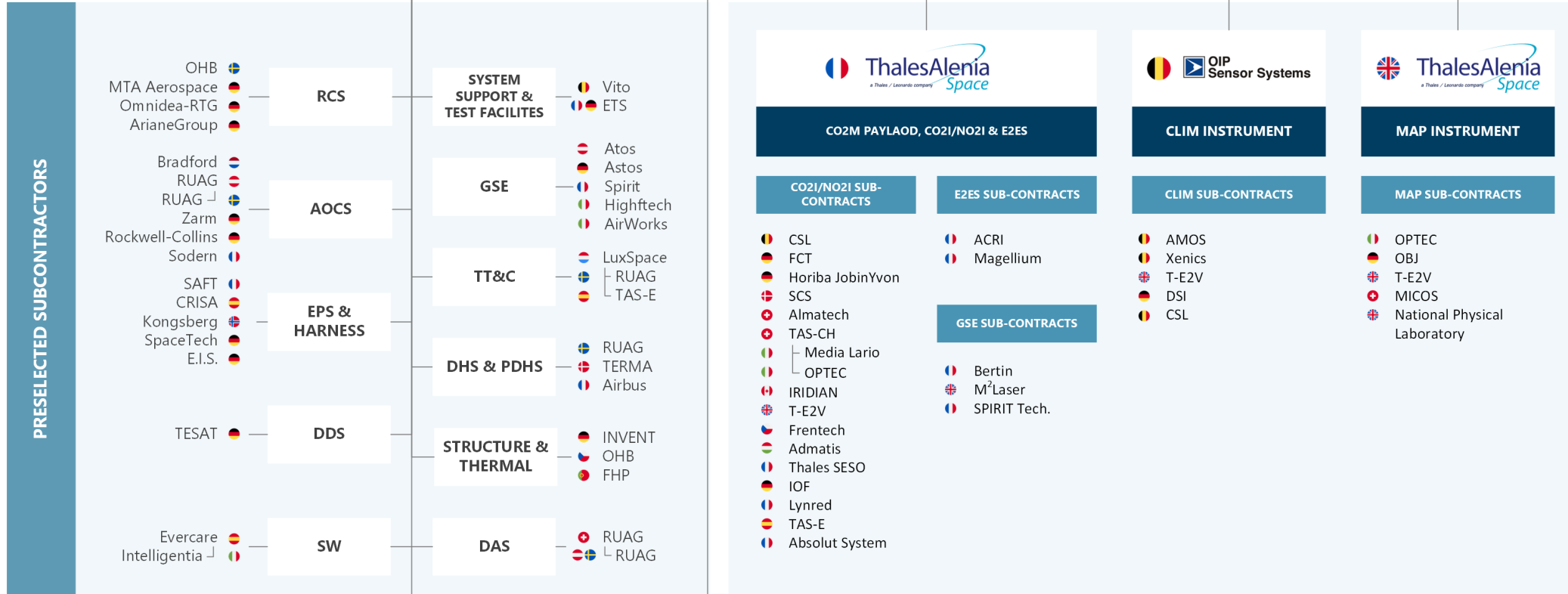
ThalesAlenia Space
a Thales / Leonardo company
CO2M PAYLAOD, CO2I/NO2I & E2ES

OIP Sensor Systems
CLIM INSTRUMENT

ThalesAlenia Space
MAP INSTRUMENT

CO2I/NO2I SUB-CONTRACTS
- CSL
- FCT
- Horiba JobinYvon
- SCS
- Almatech
- TAS-CH
  - Media Lario
  - OPTEC
- IRIDIAN
- T-E2V
- Frentech
- Admatis
- Thales SESO
- IOF
- Lynred
- TAS-E
- Absolut System

E2ES SUB-CONTRACTS
- ACRI
- Magellium

GSE SUB-CONTRACTS
- Bertin
- M²Laser
- SPIRIT Tech.

CLIM SUB-CONTRACTS
- AMOS
- Xenics
- T-E2V
- DSI
- CSL

MAP SUB-CONTRACTS
- OPTEC
- OBJ
- T-E2V
- MICOS
- National Physical Laboratory

BACKUP SLIDES

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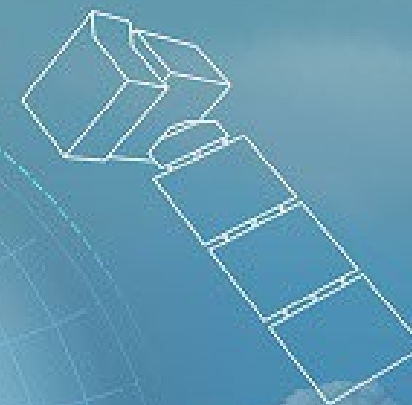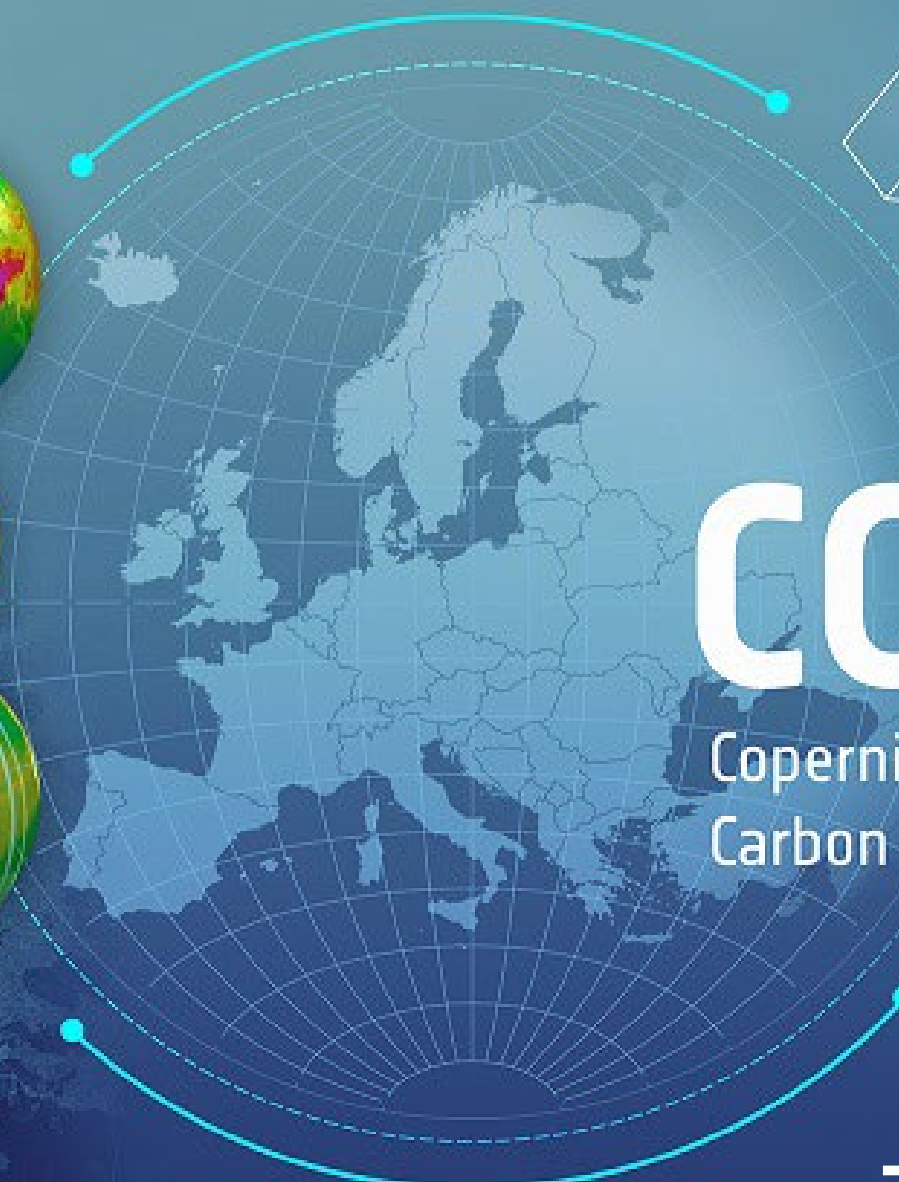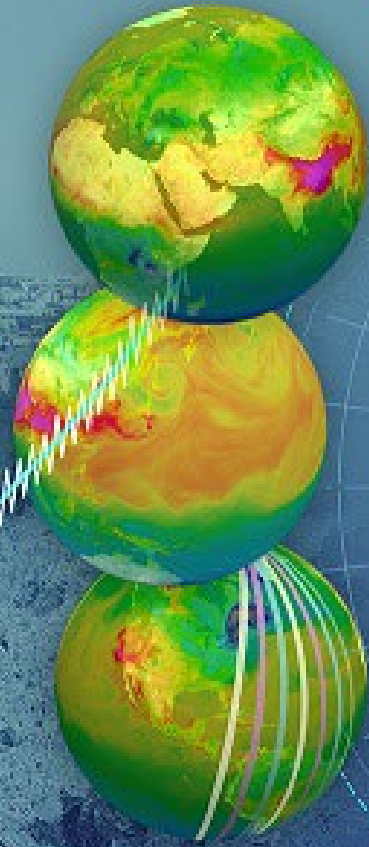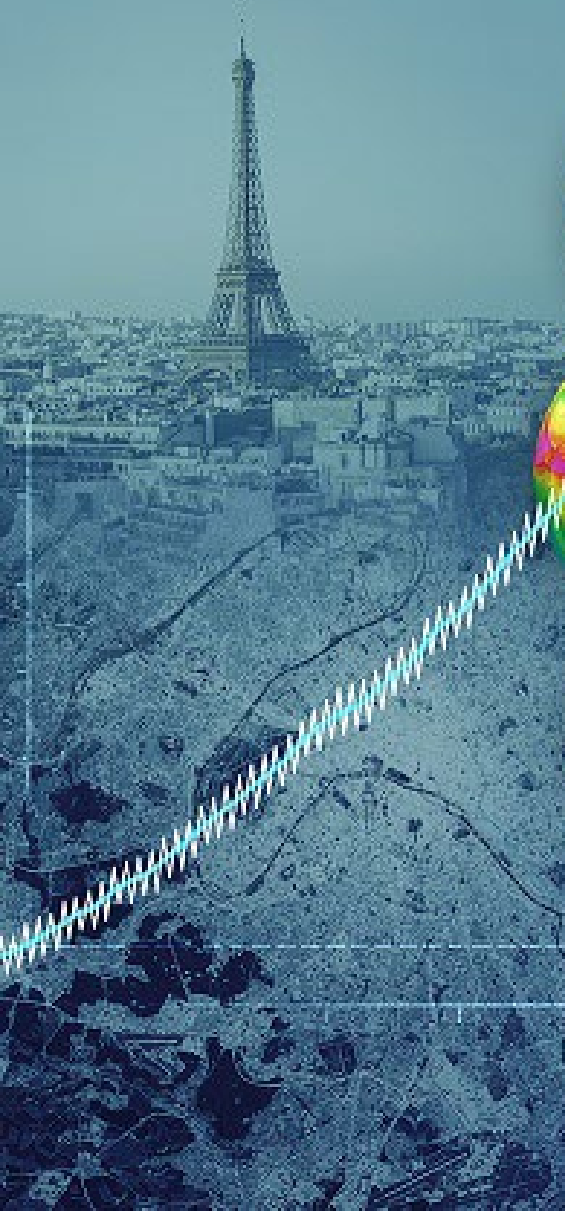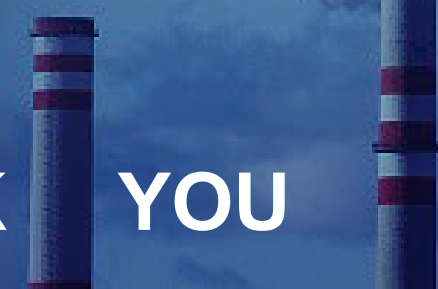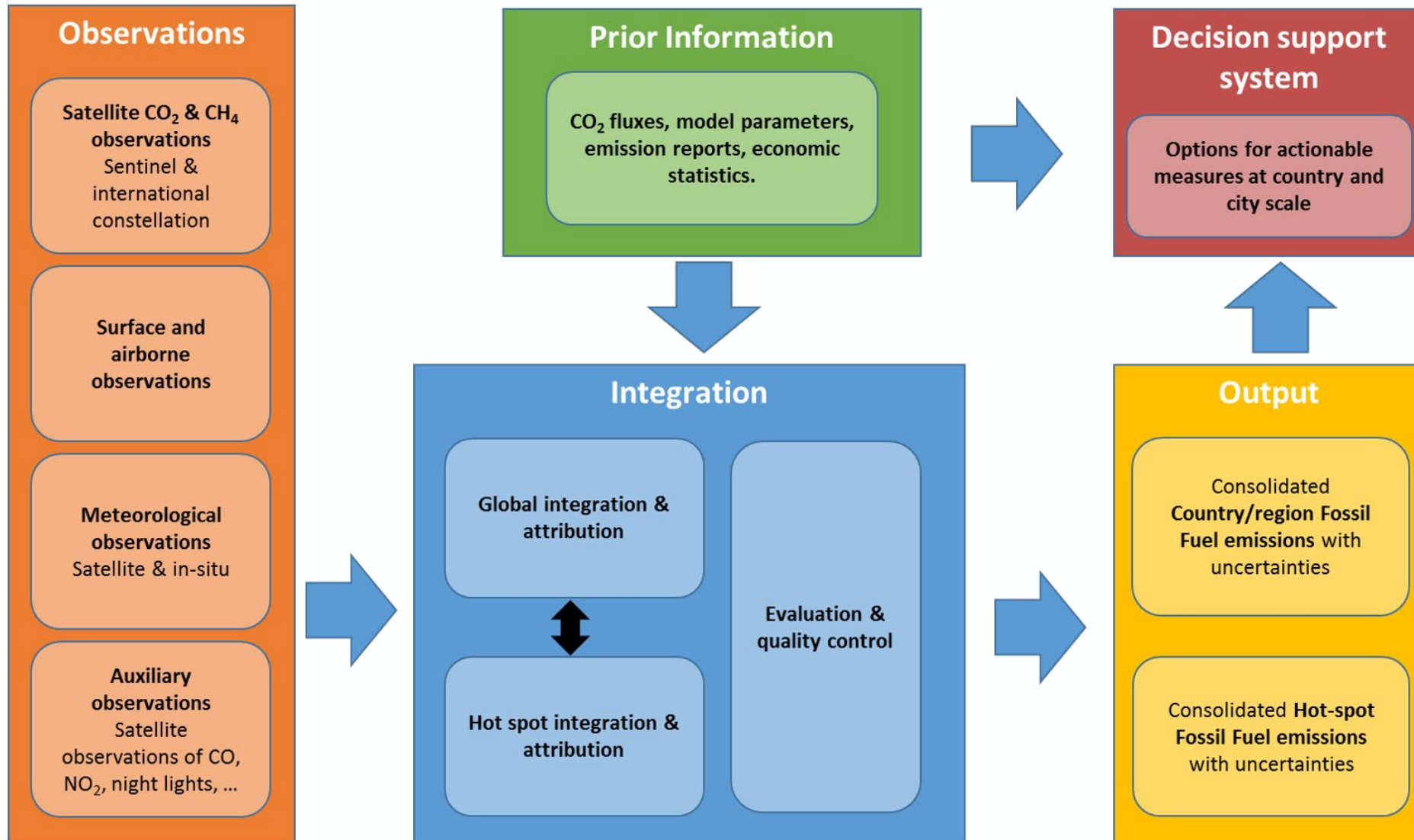
An Operational Anthropogenic CO2 Emissions Monitoring & Verification Support Capacity

Towards an anthropogenic CO_2 Monitoring & Verification Support Capacity