Operational monitoring of anthropogenic CO_2 with the European Copernicus mission

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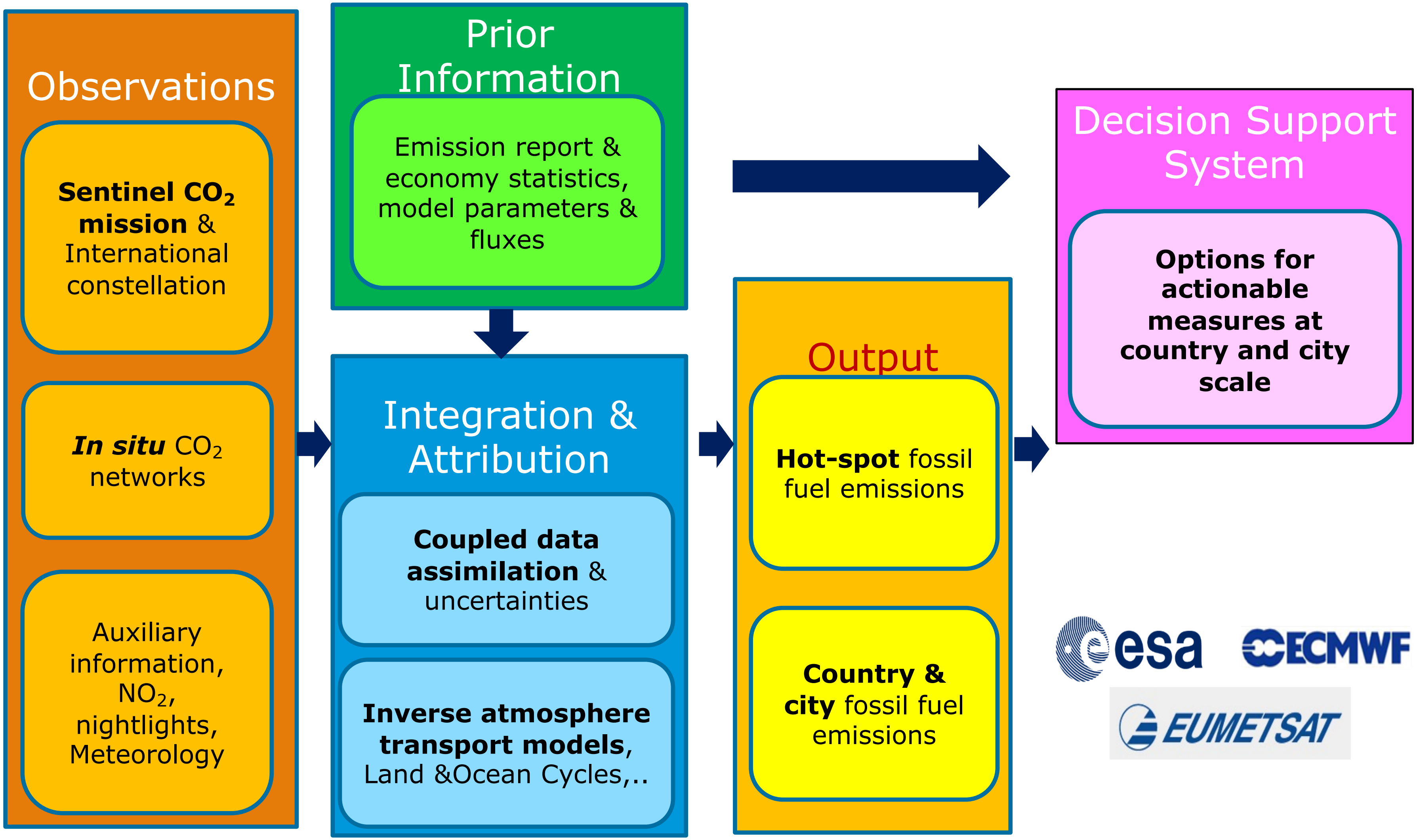
& CO_2M Phase A/B1 Study team

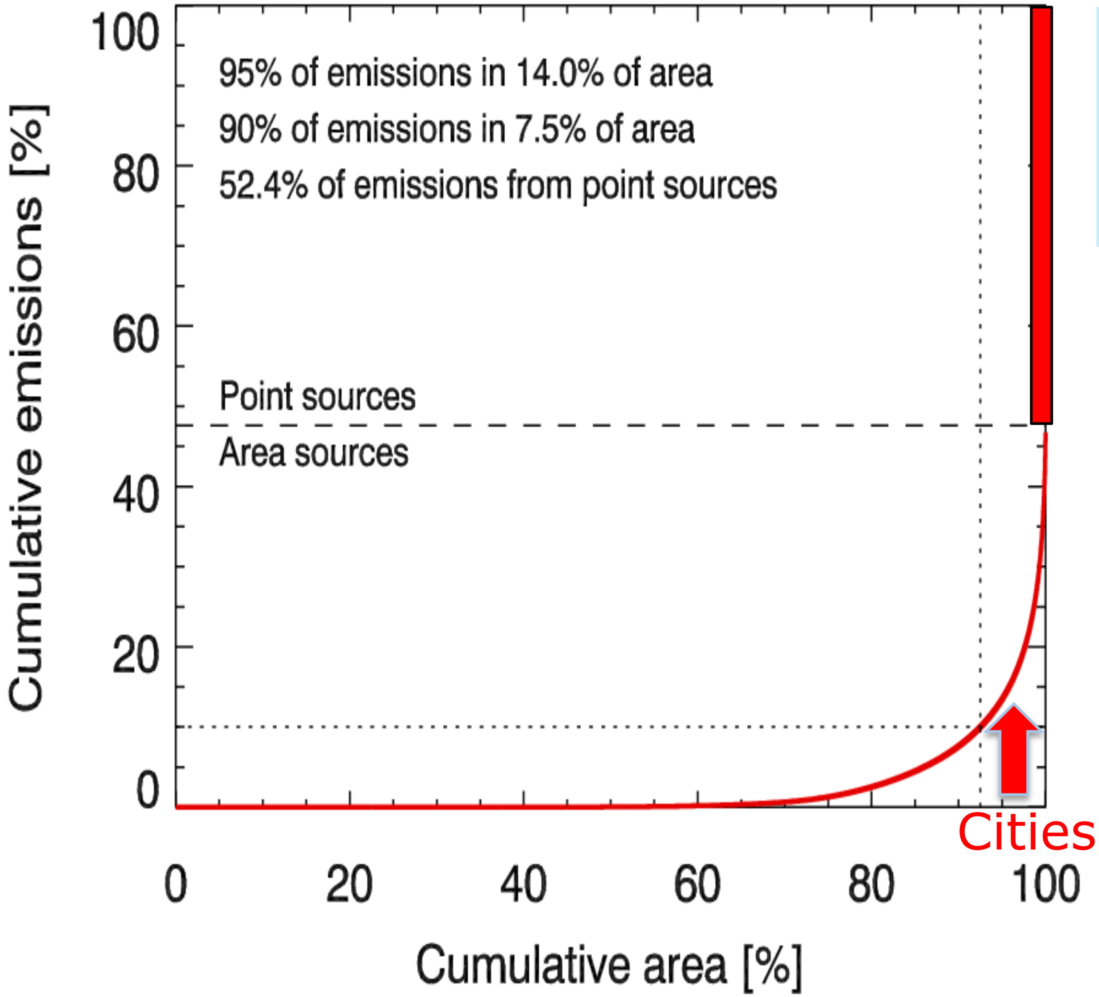
The Challenges

- UNFCCC Parties agreed for "enhanced transparency framework" (bottom-up) through national inventory reports (Paris Agreement, 2015) & complemented by global CO_2 Monitoring and verification support capacity
- Global CO_2 budget to provide input to 5-yearly global stocktake (from 2023)
- Analysis at local/regional level may support countries in evaluating the effectiveness of their CO_2 emission reduction strategies and possibly in defining revised Nationally Determined Contributions of the UNFCCC Parties
- Need to provide independent evidence on and verification of nationally reported anthropogenic CO_2 emissions and support assessing the uncertainties and gaps associated with the emission inventories

An Operational Anthropogenic CO_2 Emissions Monitoring & Verification Support Capacity



Why interest in CO_2 emissions from cities?



CO_2 emissions are mainly:

- 90% emitted over less than 8% of area of Europe
- 52% from point sources, primarily power plants

Cities account for ~70% of global CO_2 emissions
..... and have large reduction potential

Credits: EMPA, based on TNO-MACC

Candidate Copernicus Expansion Mission

End-to-end System requirements to monitor CO_2

km &
daily scales

Accuracy

1. **Detection of emitting hot spots** such as megacities or power plants.
2. **Monitoring the hot spot emissions** to assess emission reductions/increase of the activities.
3. **Assessing emission changes against local reduction targets** to monitor impacts of the NDCs.
4. **Assessing the national emissions and changes** in 5-year time steps to estimate the global stock take.

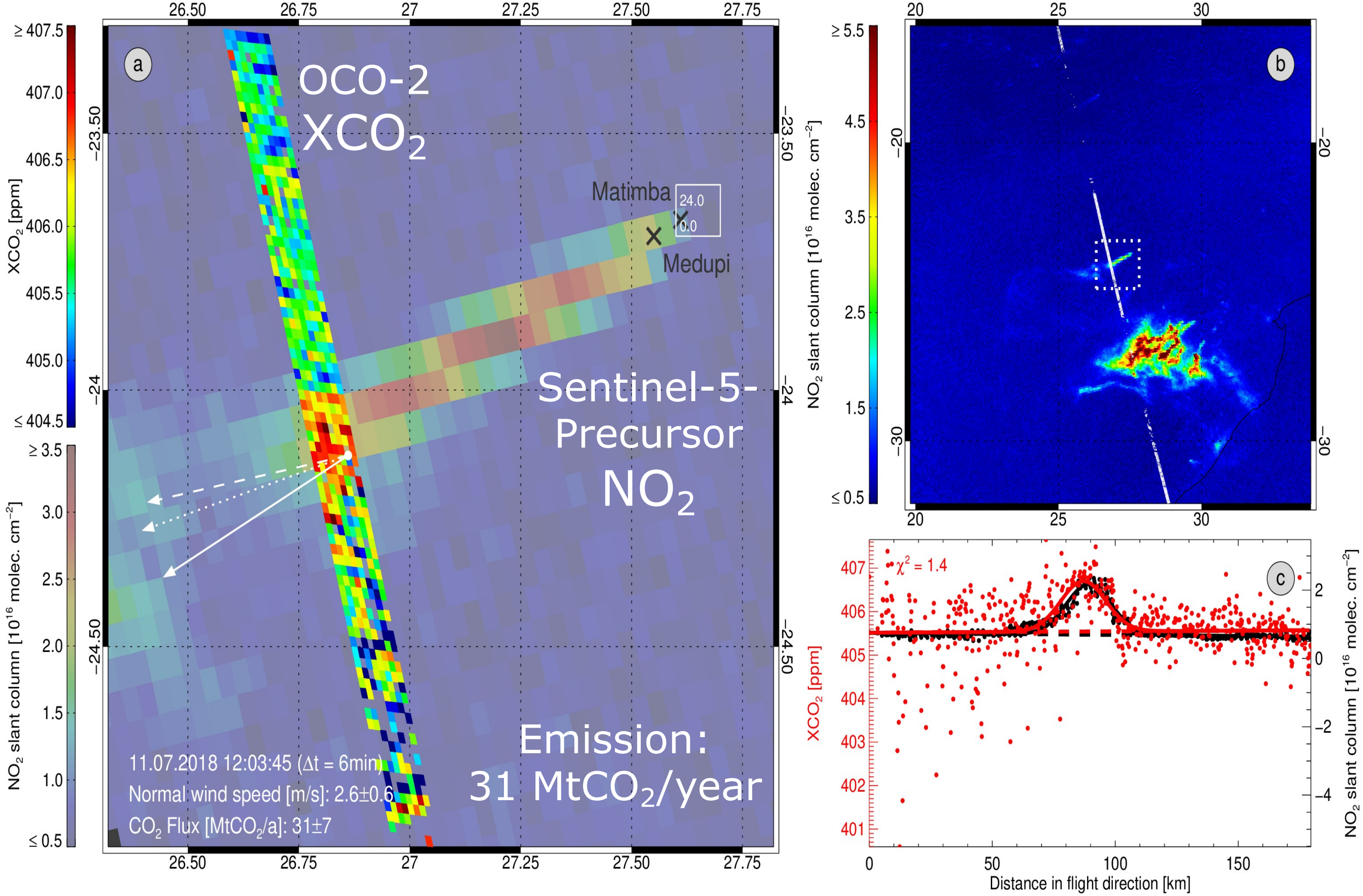
Space & Time

200-400 t/year


CO_2 Monitoring Mission
as Expansion

Imaging capabilities for CO_2 & NO_2 sources

South African power plants, on 11 July 2018



Reuter et al., ACP (submitted)

ESA

Sentinel CO2M – Products

Product	Spatial Resolution	Precision
CO_2	4 km^2	0.5–0.7 ppm
CH_4	4 km^2	10 ppb
NO_2	4 km^2	1.5 10^{15} molecules cm^{-2}
Vegetation SIF	4 km^2	0.7 mW m^{-2} sr^{-1} nm^{-1}
Aerosol params	16 km^2	0.05 AOD, 500 m LH
Cloud params	5%	Water clouds & cirrus

VIS band also covers CHO-CHO (glyoxal)

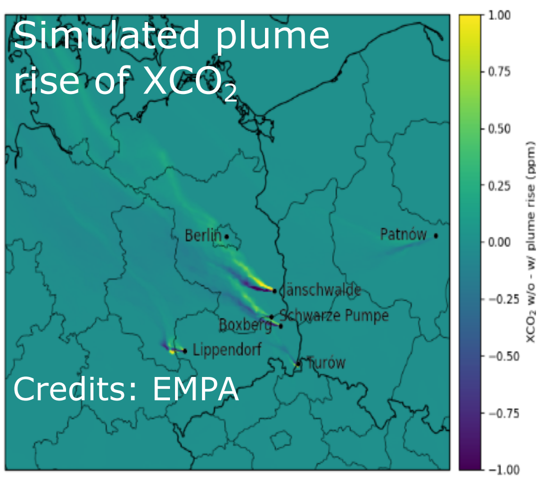
VIS & SWIR bands also cover H_2O vapour

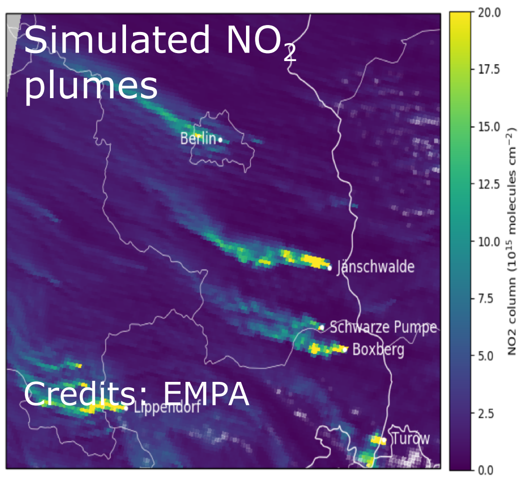
CO_2 Monitoring – Space Segment Requirements 1/4

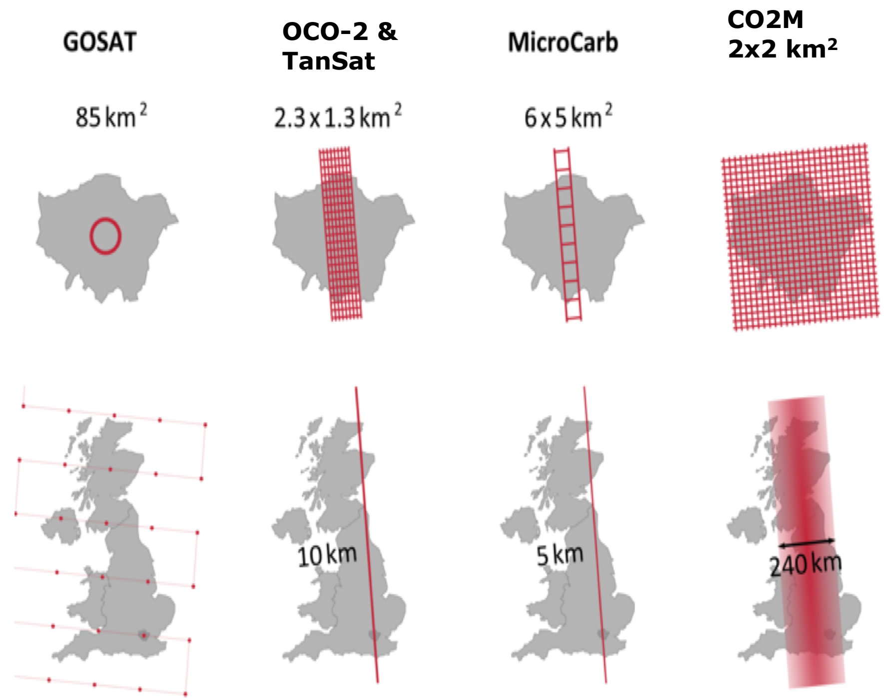
Mission requirements for XCO_2 & NO_2:

- Spatial resolution **4 km²**
- Revisit **3 days** (at ~40 deg) / **5 day global**
  XCO_2 precision: **0.5 – 0.7 ppm**
- XCO_2 systematic bias: **< 0.5 ppm**
- NO_2 precision: **$1.5 \cdot 10^{15}$ molec/cm²**
- Imaging swath **> 250 km**
- Equator crossing: **11:30 hrs**

Credits: IUP, Bremen







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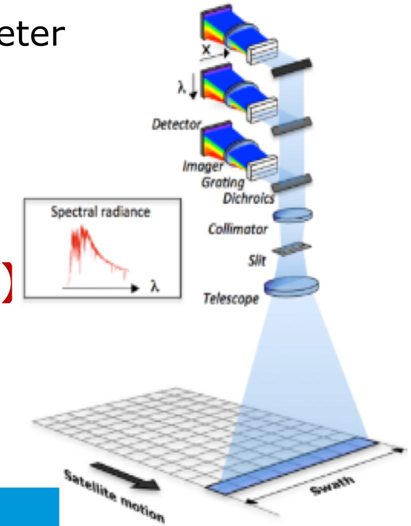
Copernicus CO2M Mission

European Space Agency

CO_2 Monitoring – Space Segment Requirements 2/4

Pusbroom imaging spectrometer

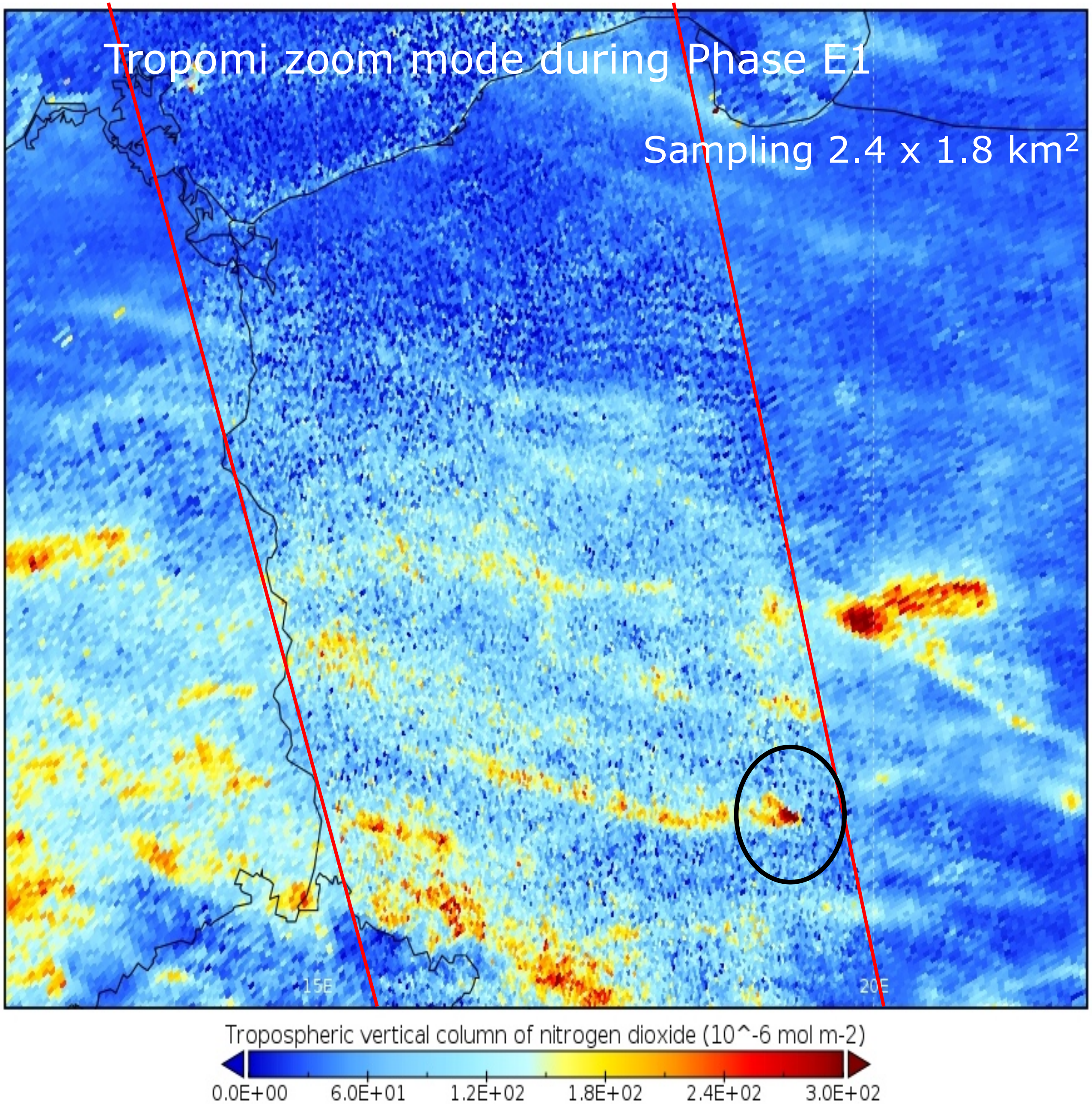


Mission requirements for XCO_2 & NO_2:

- Spatial co-registration: **95% overlap**
- Absolute radiometric accuracy: **3%**
- Effective radiometric error: **0.1%**
- ISRF shape knowledge: **2%**
- Viewing modes: **nadir (land) & sun-glint (water)**

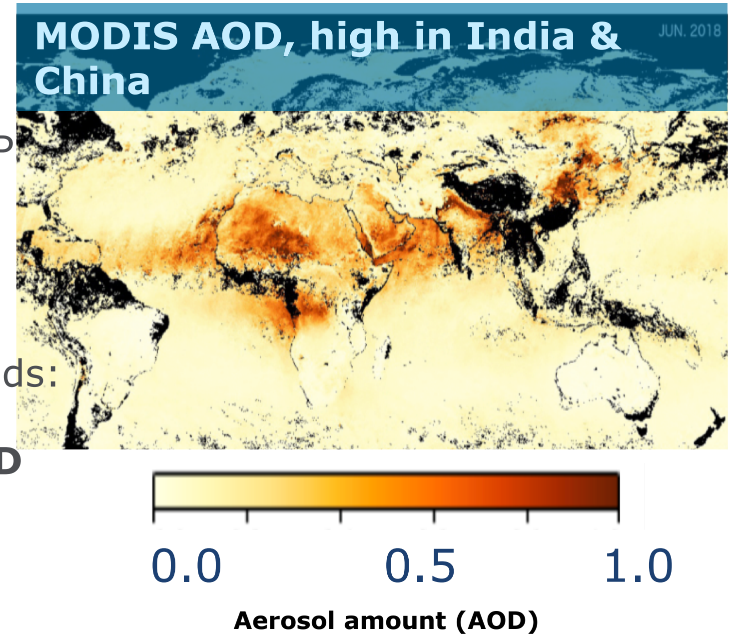
Band	Spectral range	Spectral resolution	Spectral sampling ratio	SNR_{ref} @ L_{ref} (photons/s/nm/cm^2/sr)
VIS	405–490 nm	0.6 nm	3	750 @ 1.35×10^{13}
NIR	747–773 nm	0.12 nm	3	330 @ 6.4×10^{12}
SWIR-1	1590–1675 nm	0.3 nm	3	400 @ 2.1×10^{12}
SWIR-2	1990–2095 nm	0.55 nm	3	400 @ 1.8×10^{12}

Belchatow, Poland



Credits:
KNMI &
B. Leune
TU-Delft

CO_2 Monitoring – Space Segment Requirements 3/4

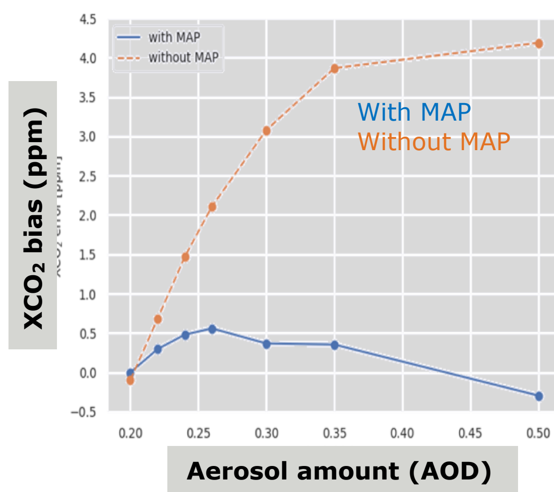


Aerosol & cloud scattering:

Light path correction is very important. Heritage missions without MAP require bias correction and strict quality filtering for AOD<0.3.
Thin cirrus & small cloud fractions also impact the retrieval beyond the required XCO_2 error budget.

For CO2M, Light path correction by measuring effective aerosol & clouds:

→ **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 1 – 5%**

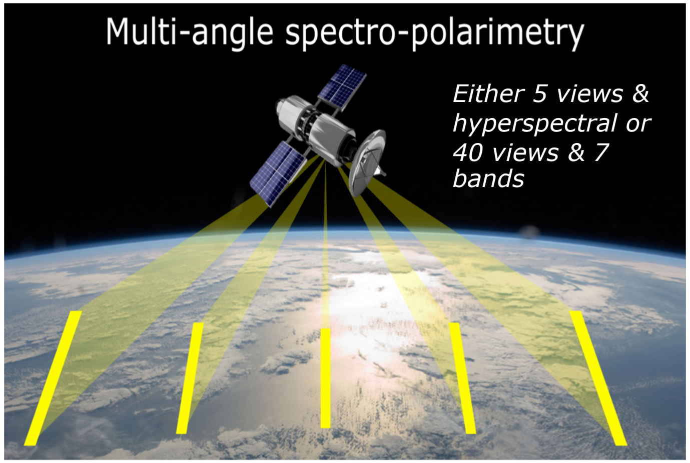


Credits: SRON, Utrecht

CO_2 Monitoring – Space Segment Requirements 4/4

Aerosol data:

- **Multi-angle polarimeter (MAP)** for light path correction
- Either 5 views continuous band **or** 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**



MAP Band	Spectral range [nm]	L^{TOA} Spectral resolution	DoLP spectral resolution
UVN	385–770	5 nm	15–40 nm

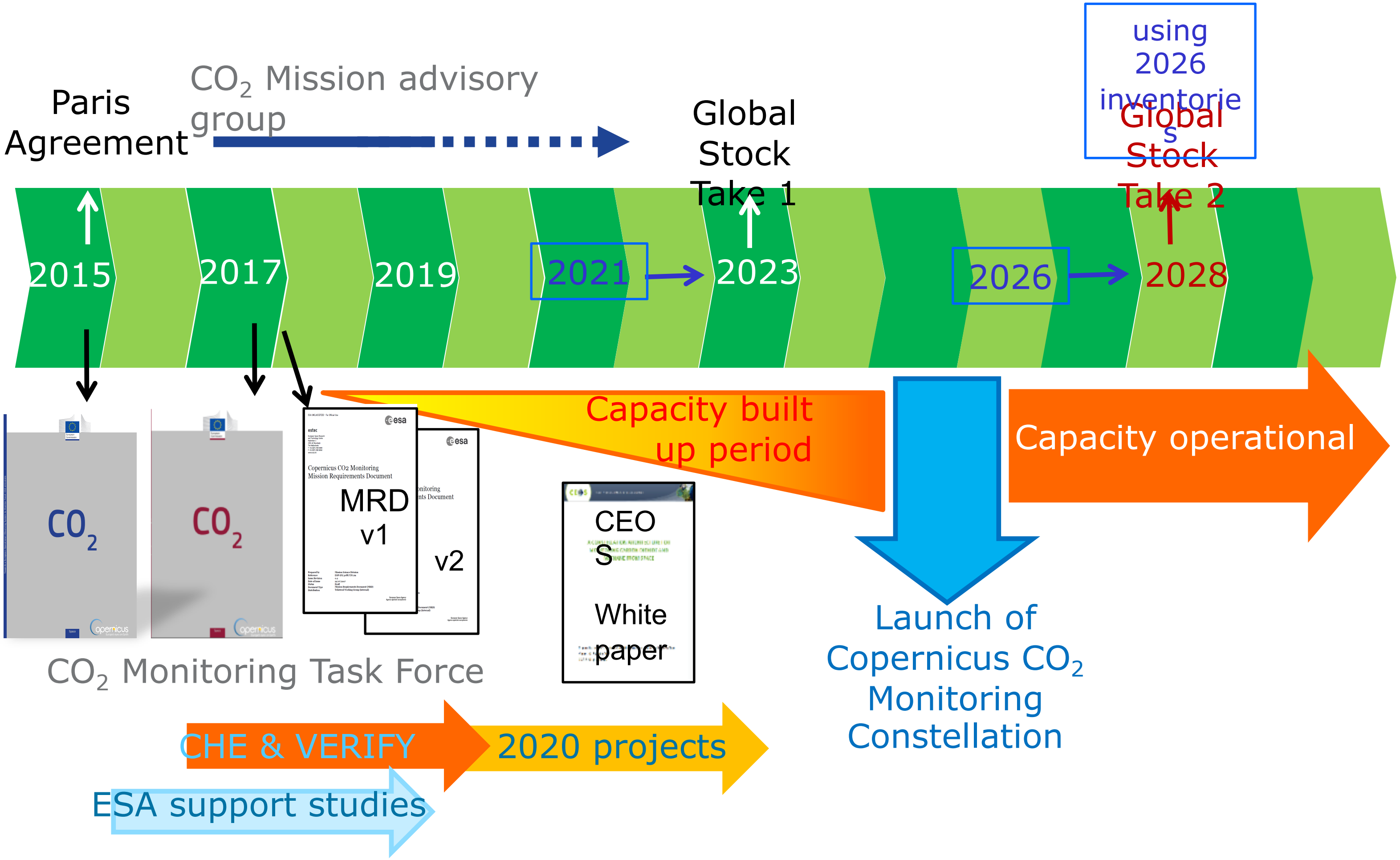
MAP Channel	Central wavelength	Spectral width
VNIR-1	410 nm	20 nm
VNIR-2	443 nm	20 nm
VNIR-3	490 nm	20 nm
VNIR-4	555 nm	20 nm
VNIR-5	670 nm	20 nm
VNIR-6	753 nm	9 nm
VNIR-7	865 nm	40 nm

Cloud Imaging (CIM)

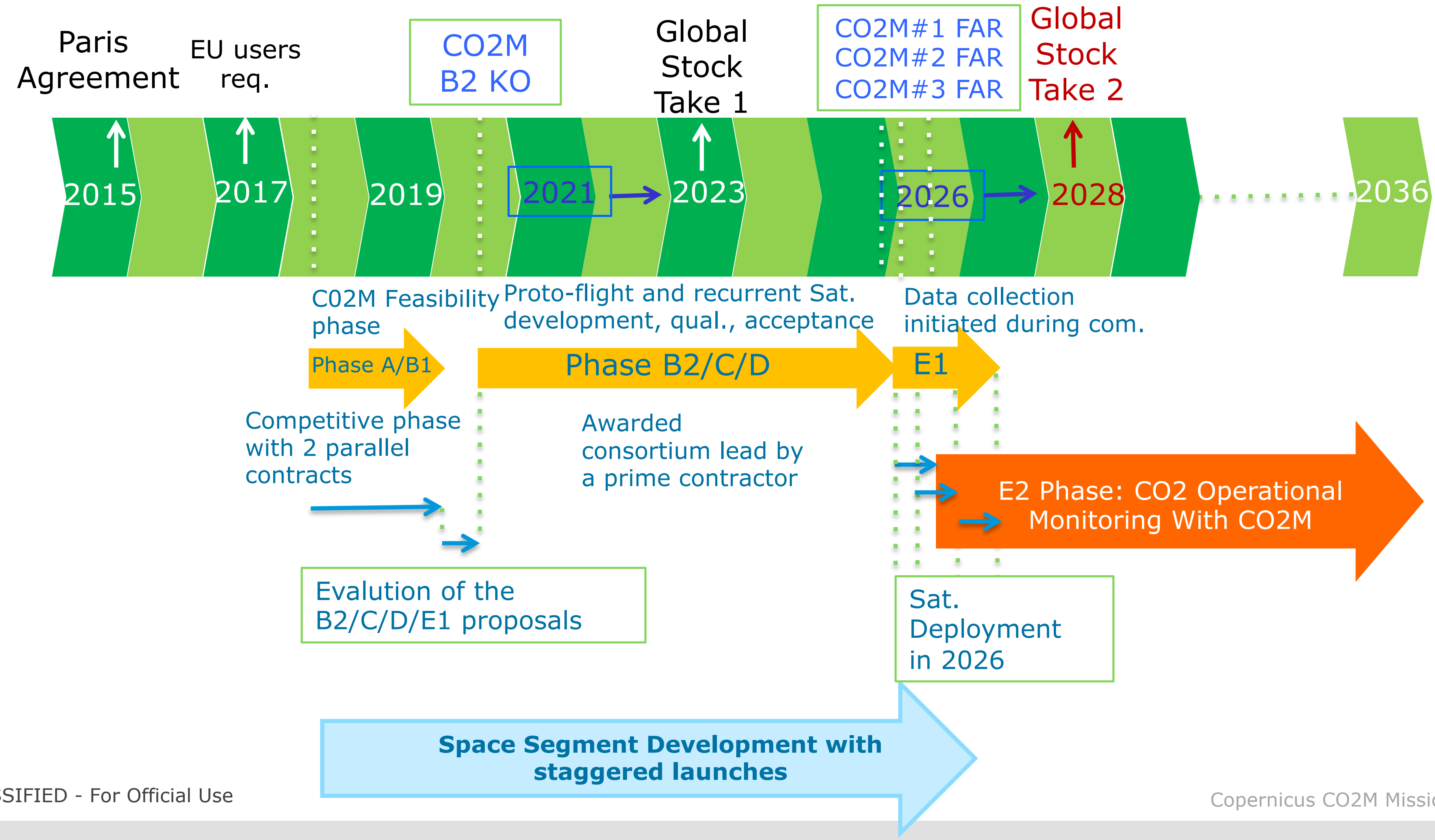
- Multi channels imager (VIS/SWIR)
- Spatial sampling **400 m**

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

Towards an anthropogenic CO_2 Monitoring & Verification Support Capacity



Towards an anthropogenic CO_2 Monitoring CO2M Space segment development



Copernicus
Europe's eyes on Earth

European Commission

EUMETSAT

ECMWF

esa
European Space Agency

Thank you

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CO_2 Monitoring Mission Advisory Group, Major international institutions

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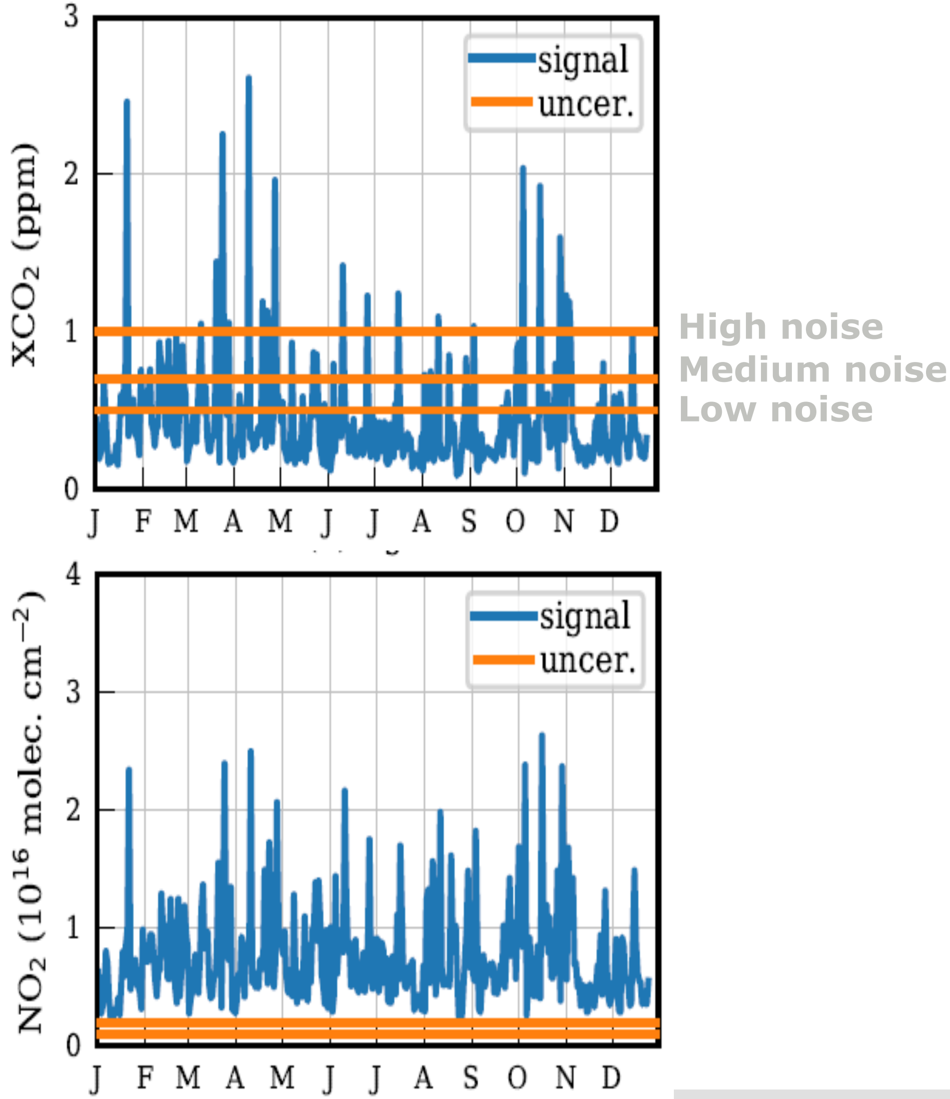
ESA, Frascati, Italy

Plume detection: noise & background variability

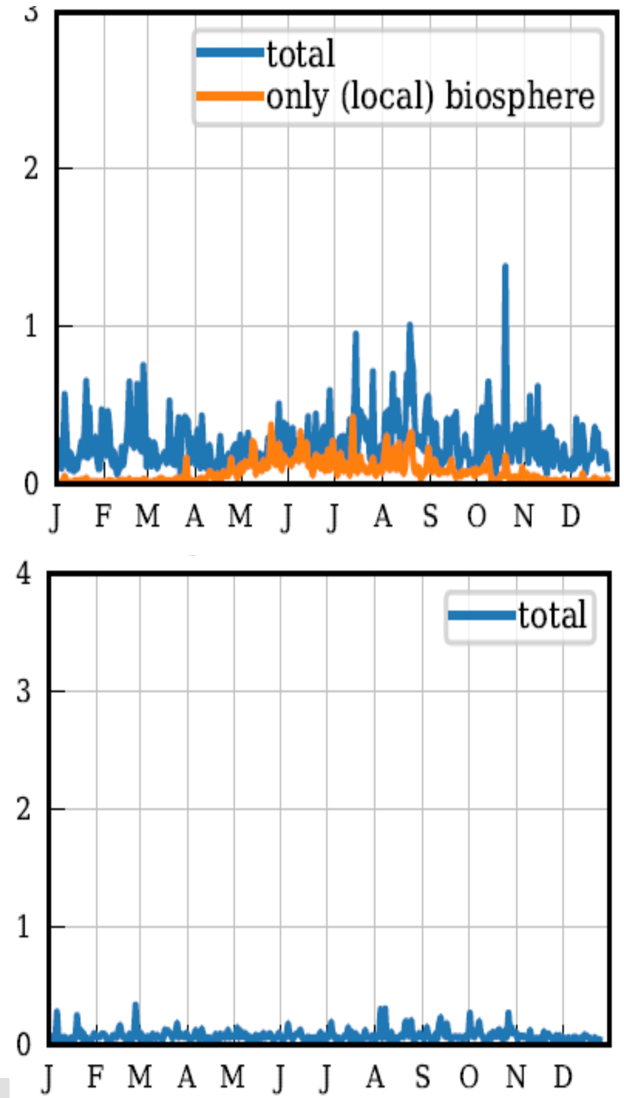
CO_2

NO_2

Berlin plume peak signal



Spatial variability of background



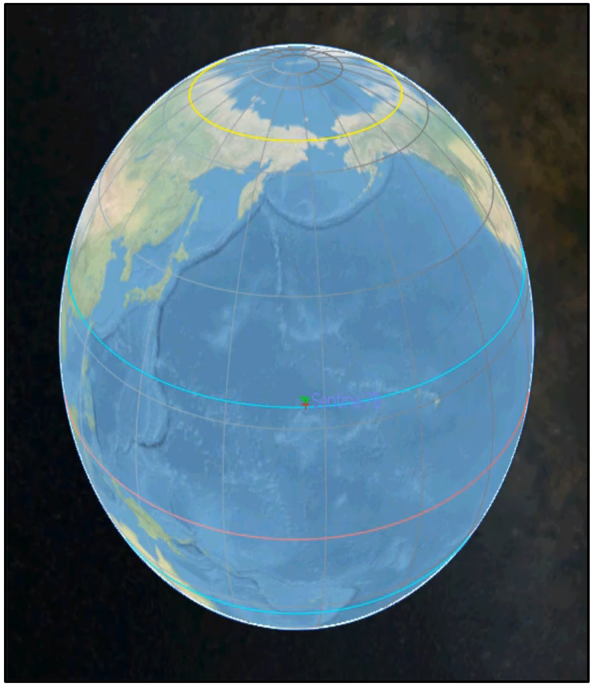
CO_2 monitoring mission status & planning

- Users requirements: CO_2 red report (Nov. 2017)
- Objectives and requirements for space component: Mission Requirements Document (MRD)
    - Version 1 finalized by Q4 2017
    - Version 2 by mid 2019
- Phase A/B1 space system activities until mid 2019
- Implementation phase targeted to start early 2020 (a.o. depending on ESA ministerial conference end 2019)
- Support the 2028 global stocktake

Sentinel GHG & CEOS collaboration

CEOS Virtual Constellation collaboration options with CO2M:

- Add CO_2 imagers in constellation → Increase coverage
- Add CO_2 lidar in constellation → calibrate imagers
- Contribute with in-situ
- Contribute with radiometric calibration
- Exploit data



Animation of constellation
with 3 satellites each
250 km swath