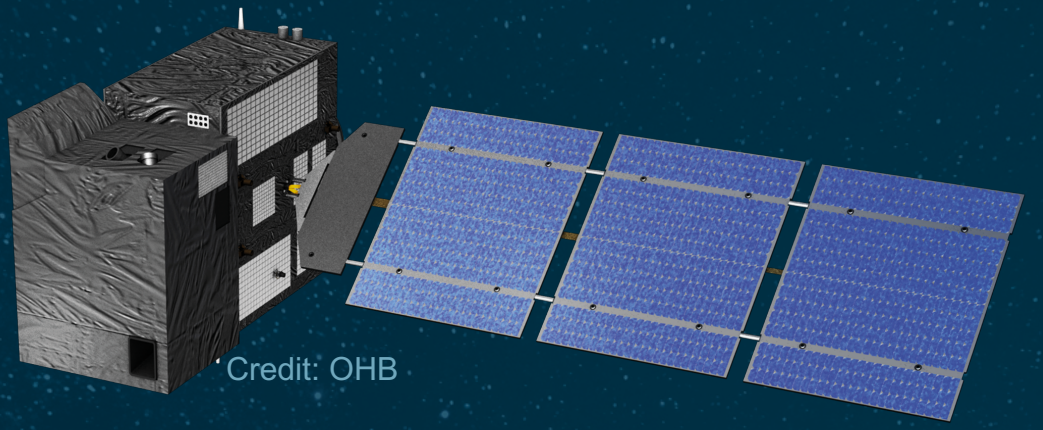
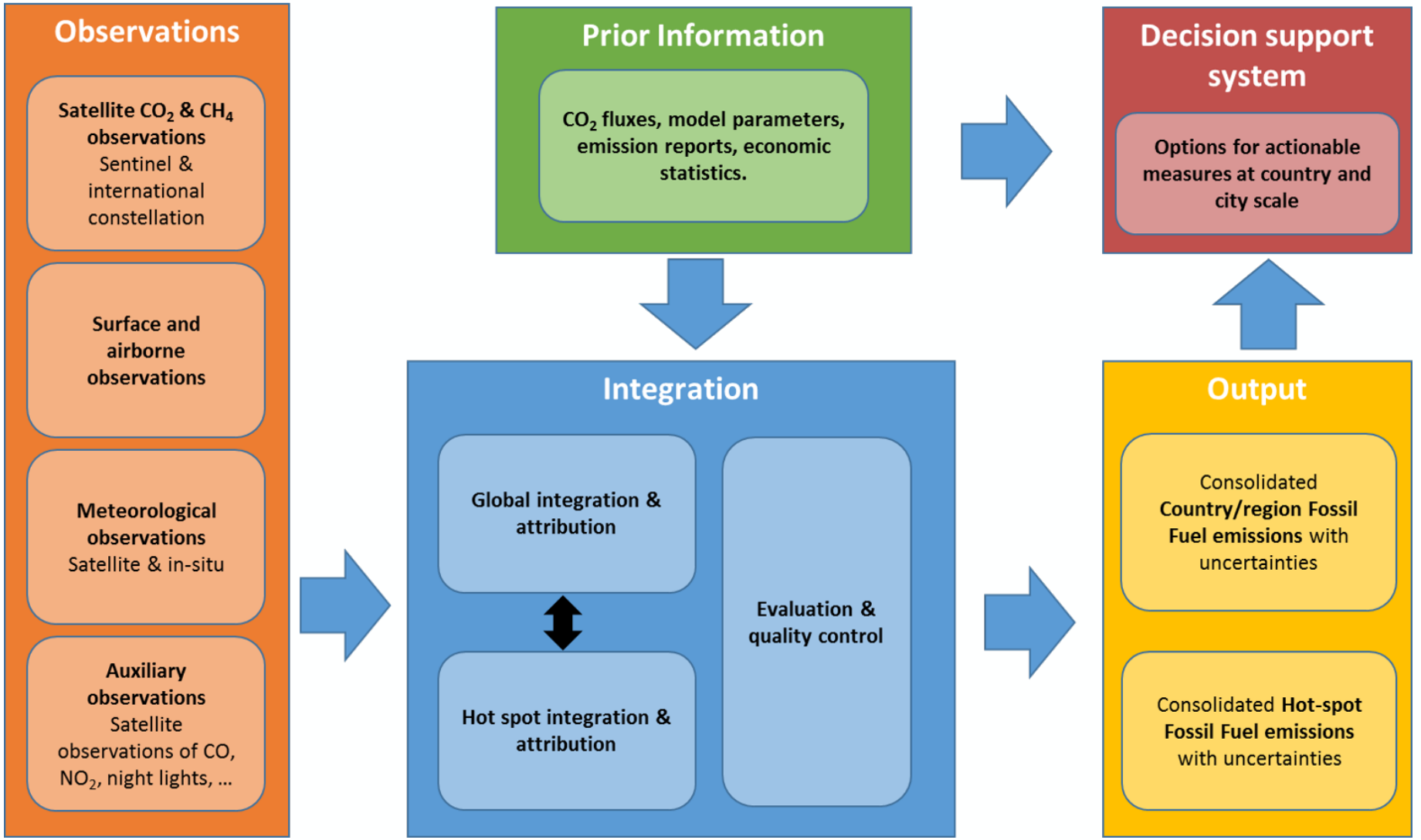

Credit: OHB

Anthropogenic Greenhouse Gas Monitoring with the Copernicus CO_2 Monitoring (CO2M) Mission

Yasjka Meijer, PhD
European Space Agency (ESA)
CO2M Mission Scientist

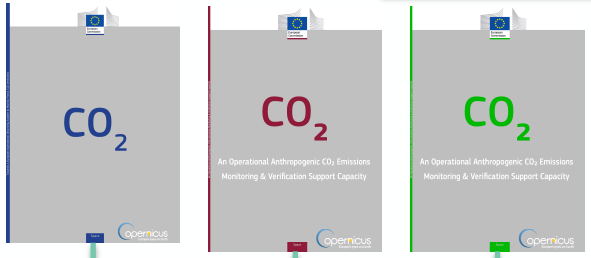
An Operational Anthropogenic CO2 Emissions Monitoring & Verification Support Capacity



Towards an anthropogenic CO_2 Monitoring & Verification Support Capacity

EU CO_2 Monitoring Task Force

CO2M Mission Advisory Group

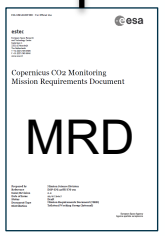


Launch of the CO2M constellation

1st global stocktake

2nd global stocktake

2015 2018 2020 2022 2024 2026 2028



Prototyping activities including relevant missions from international space agencies

Copernicus service in full operations using all CO2M Satellites and international virtual constellation

ESA & EU Science support studies

CO_2 Human Emissions

VERIFY

CoCO2 Prototype system for a Copernicus CO_2 service

EUMETSAT

Copernicus

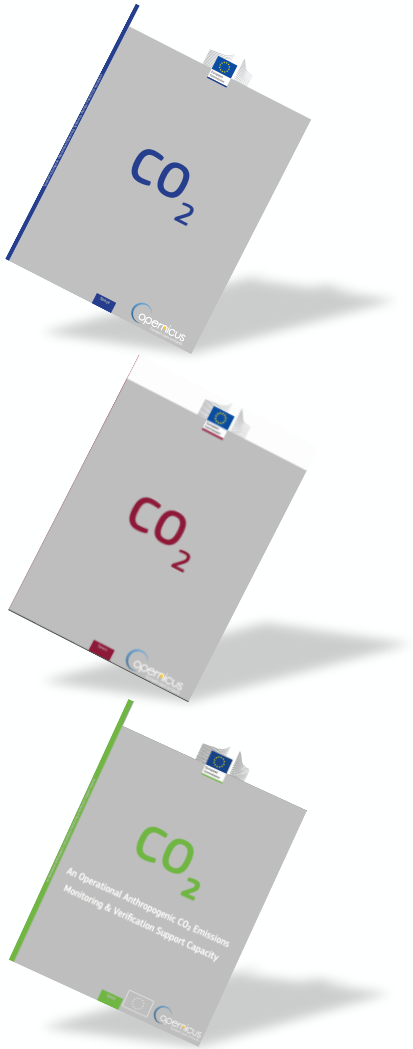
esa

ECMWF

Monitoring & Verification Support Capacity

System requirements & impact on satellite requirements

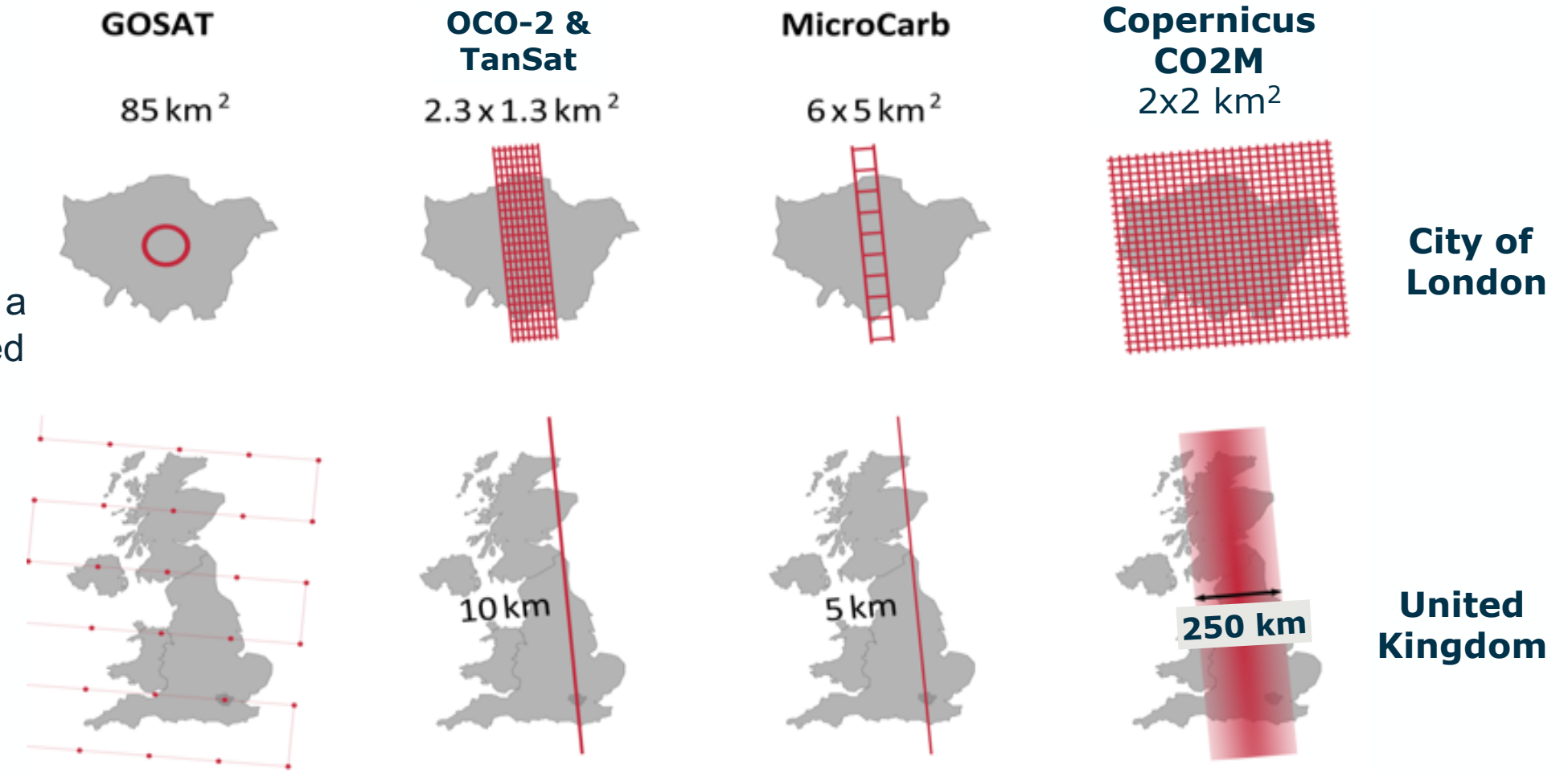
1. **Detection of emitting hot spots** such as megacities or power plants
   → **high precision CO_2 data, high spatial resolution, no local biases**
2. **Monitoring the hot spot emissions**
   to assess reductions or increase in emissions
   → **quantify emissions (plume info), frequent revisit**
3. **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**



Spatial Sampling of Various Satellite Missions

For large-scale fluxes, sampling is sufficient

For local scale fluxes, a dense mesh is required

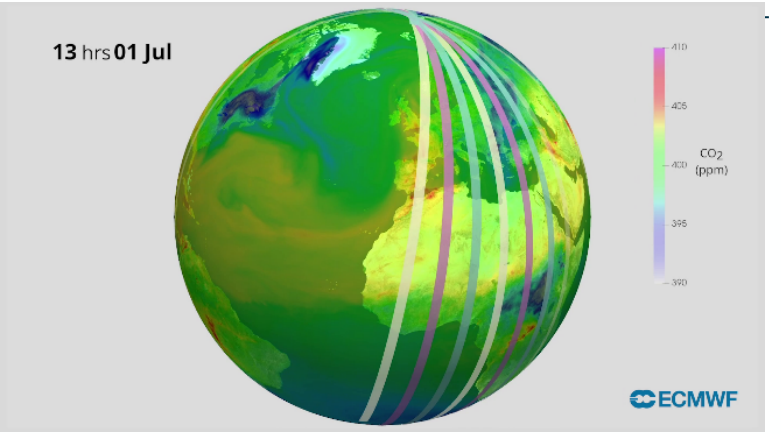


Credits: IUP, Bremen

Satellite Mission Requirements 1/2

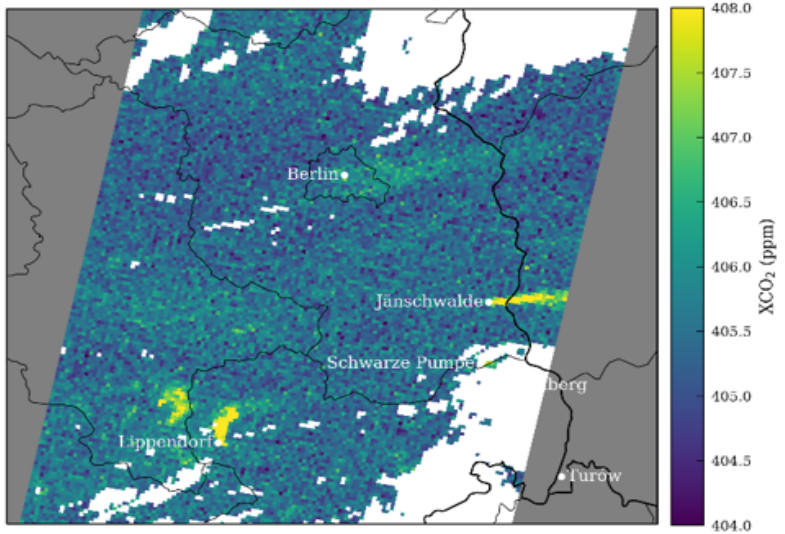
Mission requirements for CO_2 , CH_4 & NO_2:

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



Credits: EMPA

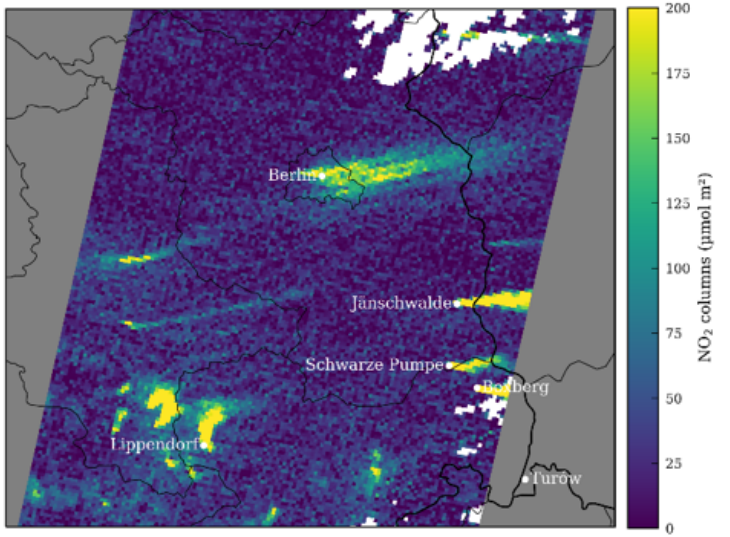
Simulated CO_2 plumes



Germany with Berlin and power plants

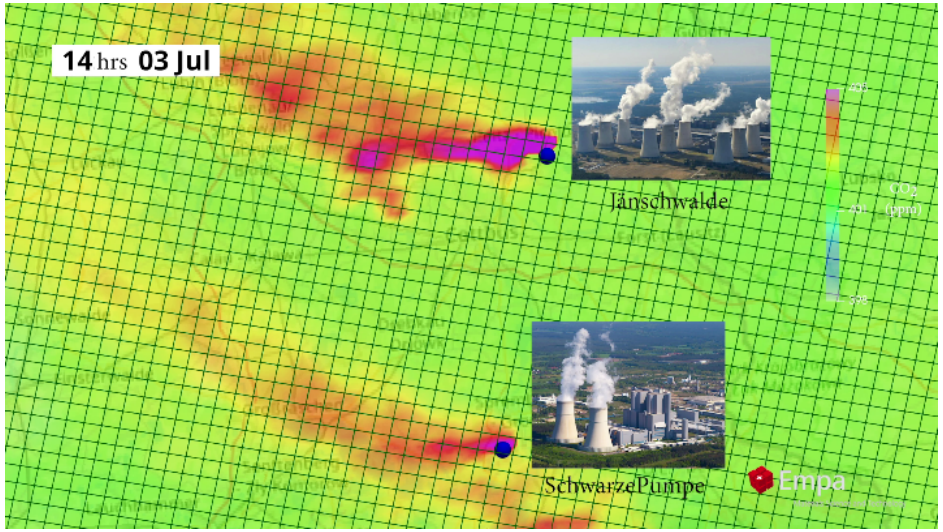
Credits: EMPA

Simulated NO_2 plumes



Credits: EMPA

Simulated CO_2 at 2x2 km² grid



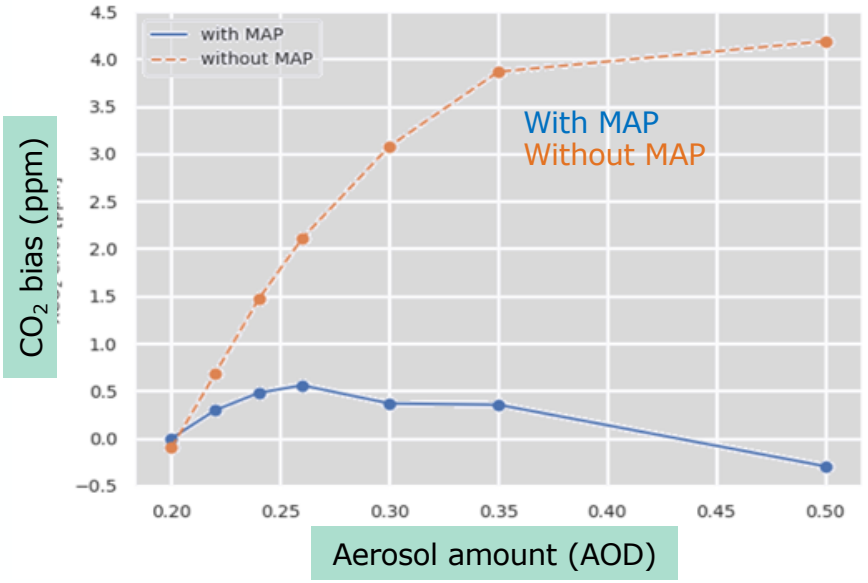
Power plants near Berlin, Germany

Credits: EMPA

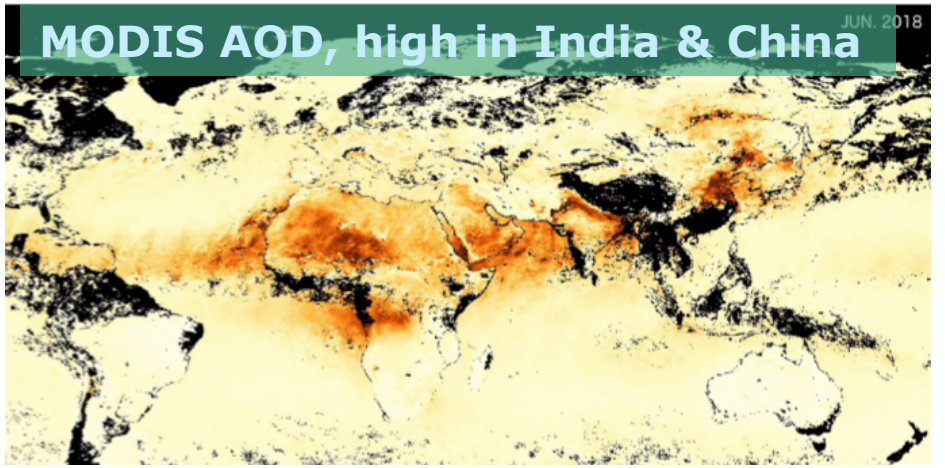
Satellite Mission Requirements 2/2

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

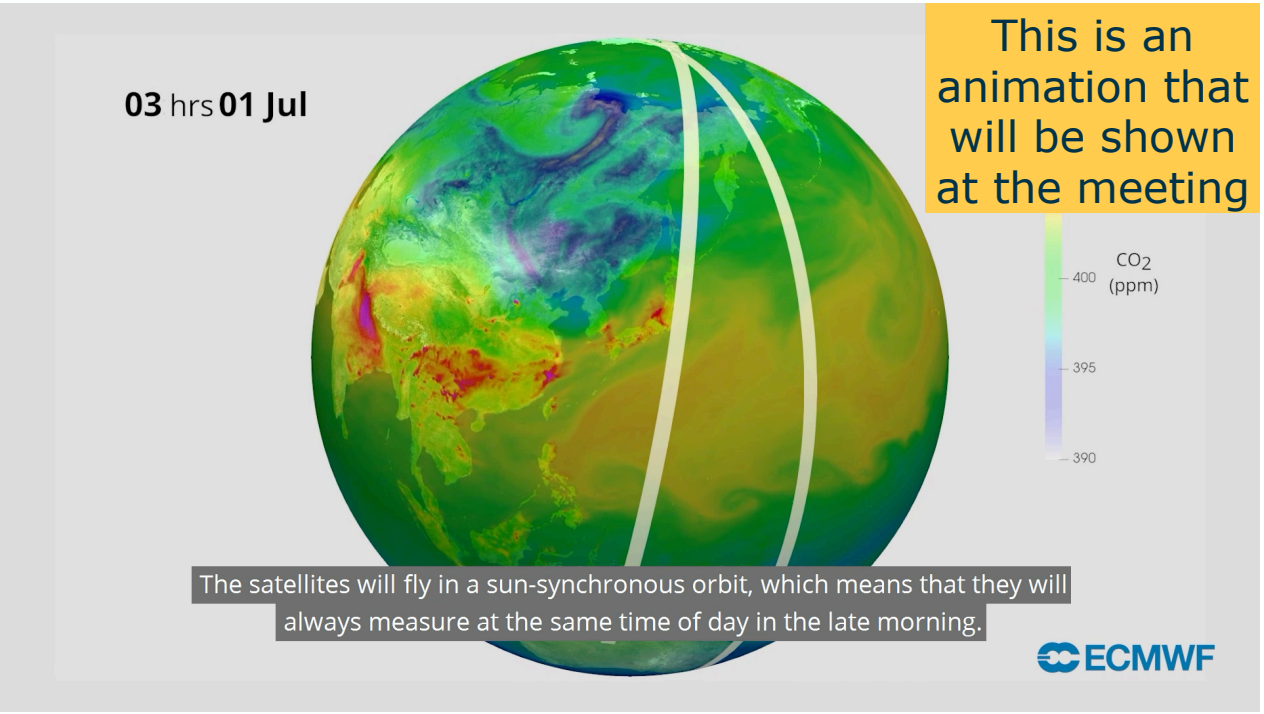


Credits: SRON

Copernicus CO2M Mission – Status

Project status:

- Preparatory phases completed in **2014–2019**
- Implementation phase started in **July 2020**
- Implementation on schedule **in 2022**
- **Constellation** of satellites
- Each satellite **>250 km swath**
- First and second satellite to be delivered in **October 2025**
- First launch forecasted by **end of 2025**



Credits: EMPA

Mission Requirements Document (MRD); applicable version with all details, see https://esamultimedia.esa.int/docs/EarthObservation/CO2M_MRD_v3.0_20201001_Issued.pdf

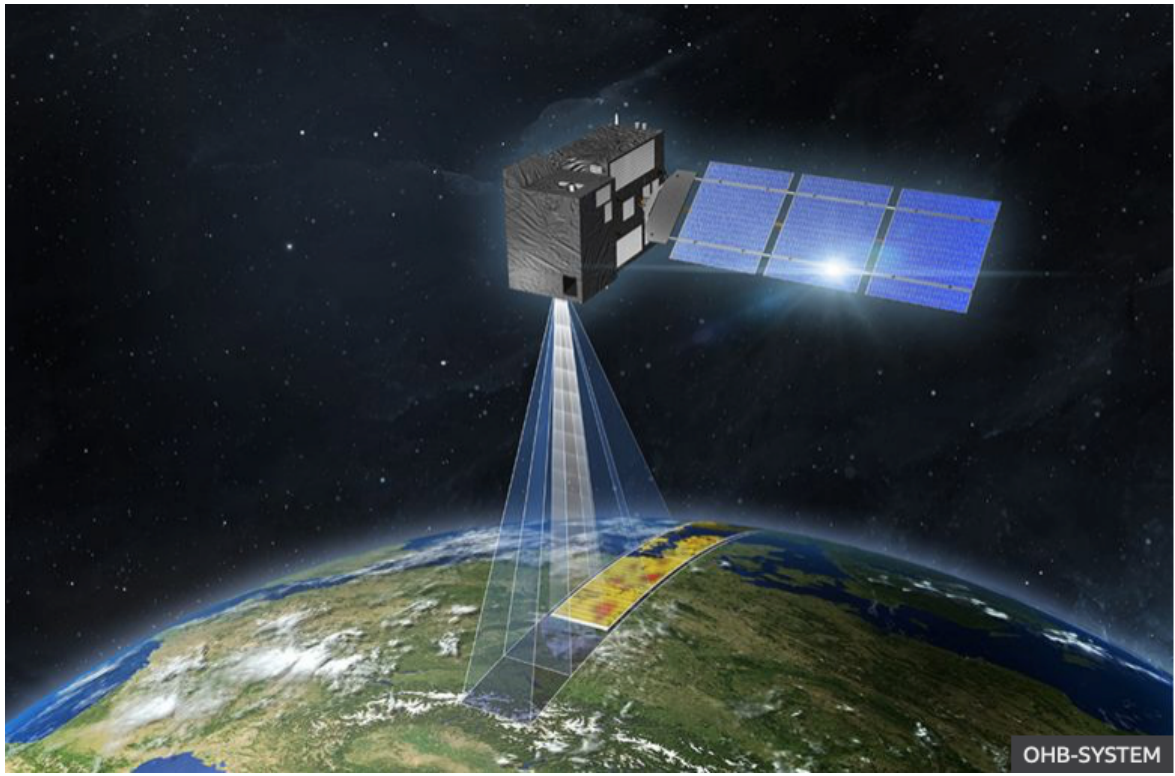
Copernicus CO2M Mission Products

Main Products	Spatial resolution	Precision
CO_2	4 km^2	0.7 ppm
CH_4	4 km^2	10 ppb
NO_2	4 km^2	$1.5x10^{15}$ $molec/cm^2$
Veg. SIF*	4 km^2	0.7 $mW\ m^{-2}\ sr^{-1}\ nm^{-1}$

*Vegetation Solar Induced Fluorescence → indicator of biogenic activity

Copernicus data is made available and accessible to any citizen, and any organisation around the world **free, full, and open basis**

EUMETSAT performs operational data processing



Credits: OHB

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

International Opportunities

International collaboration:

- International organizations: CEOS, WMO, GEO
- Ground-based networks

Opportunities to Enhance the Space-based Monitoring Efforts:

- Add CO_2 & CH_4 imagers in constellation → Increase coverage (i.e. time/space sampling)
- Add CO_2 & CH_4 lidar in constellation → (inter-)calibrate satellites
- Contribute with in-situ, ground-based and air-borne observations
- Process satellite data
- Scientific interpretation of data

"The Copernicus CO2M mission will support the climate crisis, and the objectives of the Paris Agreement and EU's Green Deal toward decarbonisation of Europe until 2050",
Simonetta Cheli – Director of Earth Observation Programmes at ESA

Backup material

- Background documentation on
  Copernicus Monitoring & Verification Support Capacity

- Example of using machine learning to detect methane emissions by analysing existing satellite data

- Example of existing observations showing large methane emissions from Australian coal mines

Monitoring & Verification Support – Context

Three reports have been issued by the European Commission

These (so-called) CO_2 reports are available at
https://www.copernicus.eu/sites/default/files/2019-09/CO2_Blue_report_2015.pdf
https://www.copernicus.eu/sites/default/files/2019-09/CO2_Red_Report_2017.pdf
https://www.copernicus.eu/sites/default/files/2019-09/CO2_Green_Report_2019.pdf

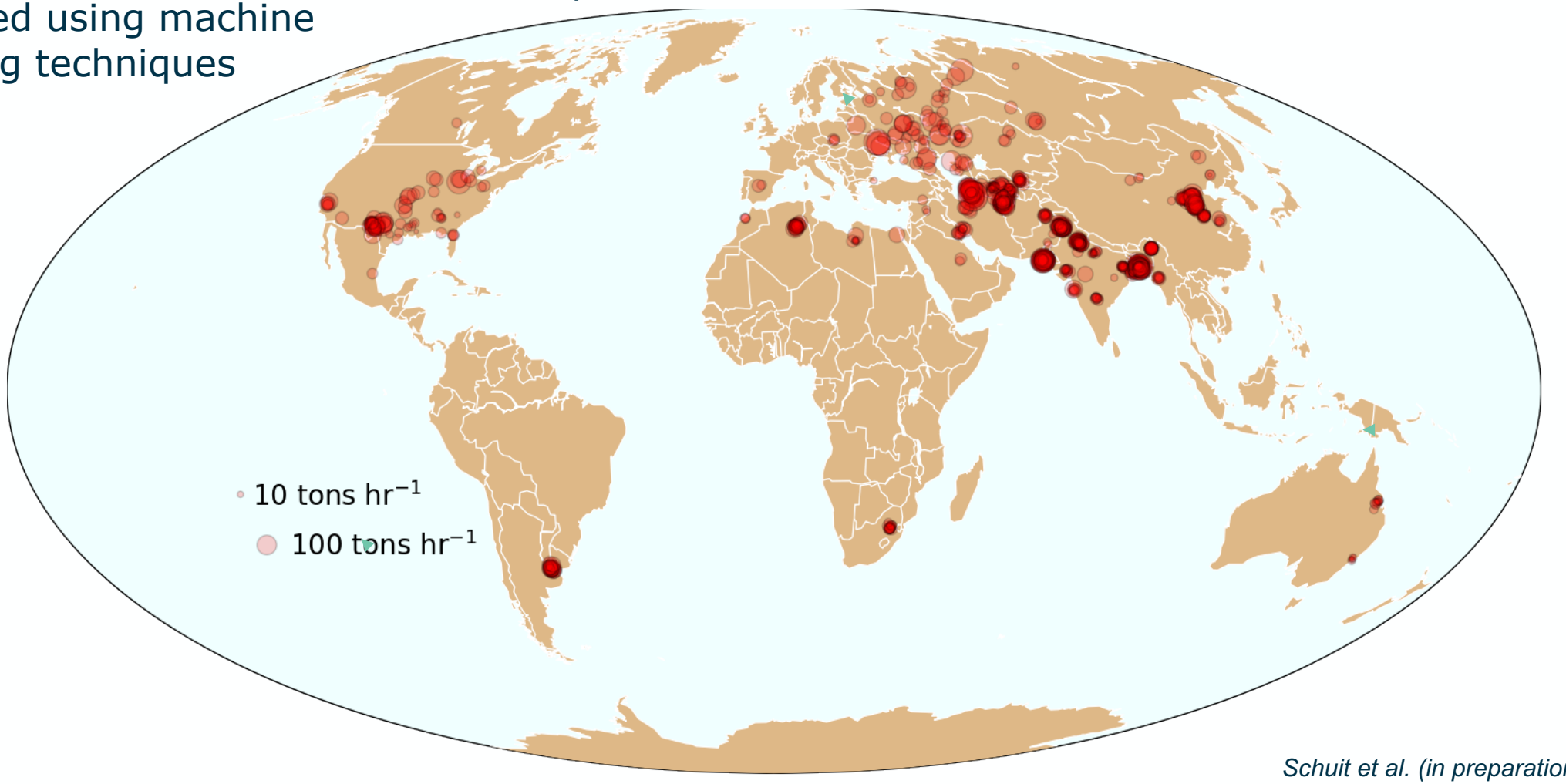
An animation of the system and its objectives can be viewed here:

https://www.youtube.com/watch?v=ZiFEe7IN2Go

Detecting methane plumes worldwide

Methane super-emitters detected using machine learning techniques

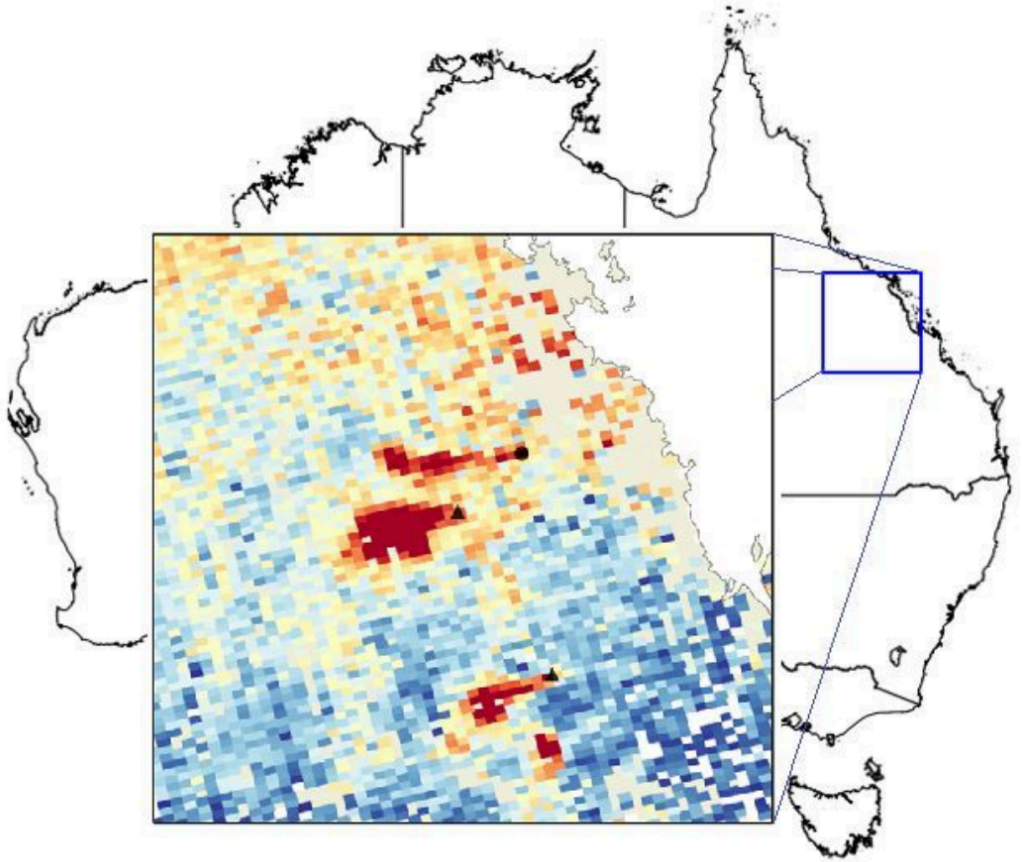
Copernicus Sentinel-5P satellite data 2020



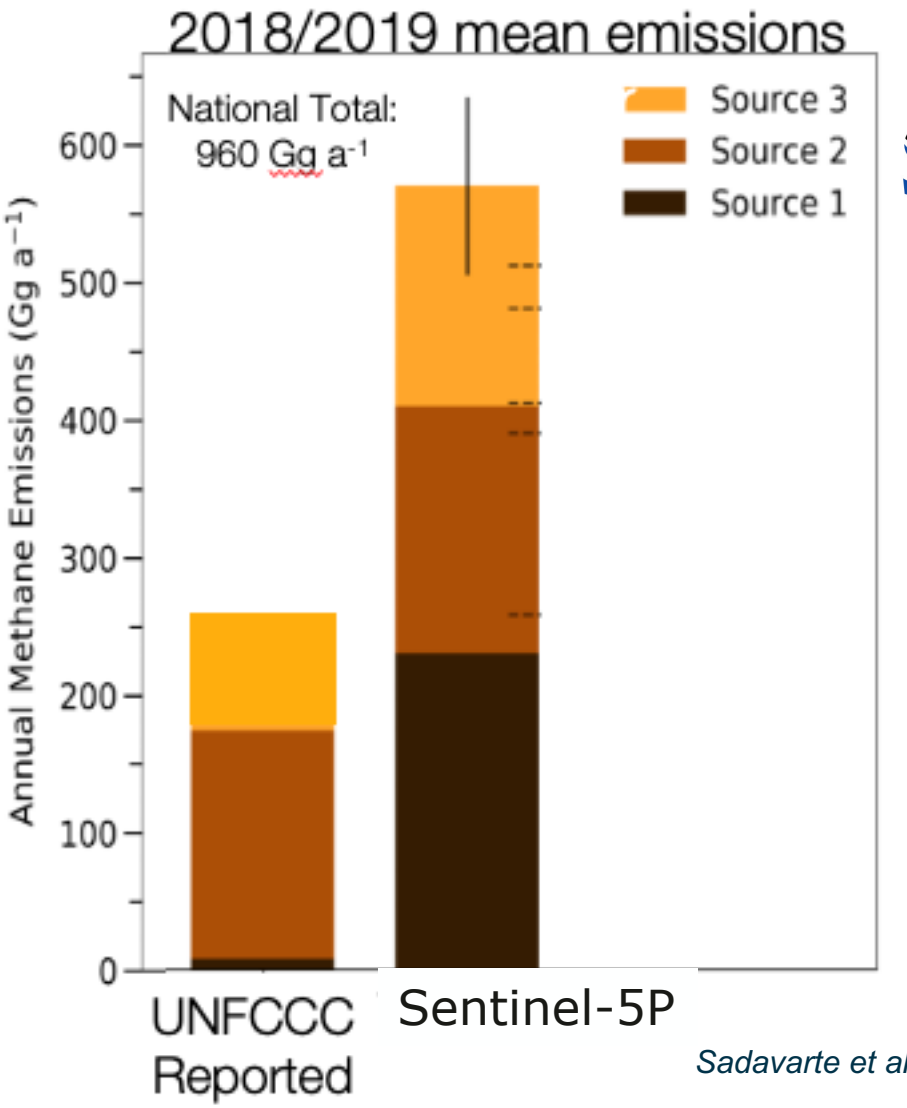
Schuit et al. (in preparation)

Methane emitting Australian coal mines

Methane by Copernicus Sentinel-5P satellite



Three super emitting coal mines. One mine here is responsible for 1% of national coal production and has estimated 24% of reported emissions of all coal mines.



Sadavarte et al., ES&T, 2021