An overview of Copernicus' greenhouse gas satellite missions

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Contributions from many experts
Major international institutions

Copernicus Satellite Missions

- **S1:** Radar Mission
- **S2:** High Resolution Optical Mission
- **S3:** Medium Resolution Imaging and Altimetry Mission
- **S4:** Geostationary Atmospheric Chemistry Mission
- **S5:** Low Earth Orbit (LEO) Atmospheric Chemistry Mission
- **S5P:** LEO Atmospheric Chemistry Precursor Mission
- **S6 (Jason-CS):** Altimetry Mission

METHANE

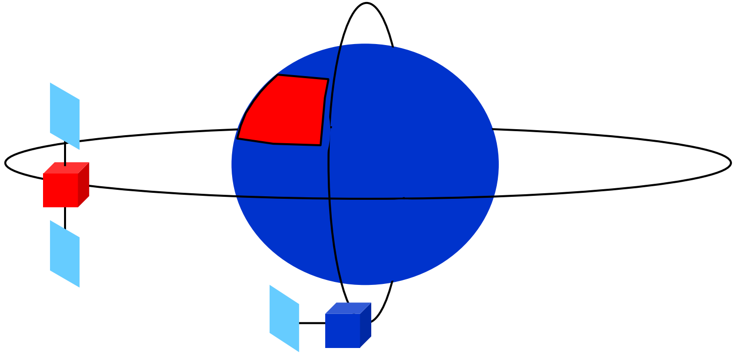
METHANE

European Commission

Sentinel Missions Dedicated to Atmosphere

Sentinel-4

- Geostationary
- Hourly revisit time
- Europe



Sentinel-5 & -5 Precursor

- Low Earth Orbit
- Daily revisit time
- global coverage

2021–2040

	Sentinel-4 focus on short lived species in troposphere	**Sentinel-5 / 5P** covers also long lived species in troposphere and stratosphere
Air Quality	NO_2, O_3, aerosol, SO_2	NO_2, O_3, aerosol, SO_2, CO
Climate	aerosol, O_3	CH_4, CO, aerosol, O_3
Ozone & UV	O_3, cloud, aerosol	O_3, cloud, aerosol
Emissions	NO_2, SO_2, aerosol, HCHO, CHOCHO	NO_2, SO_2, aerosol, HCHO, CO, CH_4

Possible Evolution: Interim Conclusion

Needs to be investigated within Copernicus:

Priority 1:

Greenhouse gas monitoring, specifically anthropogenic CO_2 emissions

Priority 2:

Monitoring the Polar regions, specifically the Arctic for sea ice and icebergs

Monitoring Agriculture, specifically on parameters which potentially could be addressed through thermal infrared observations

Priority 3:

Mining, biodiversity, soil moisture and other parameters, requiring observations in additional bands currently not available

CO_2 Monitoring Mission Objectives

The anthropogenic CO_2 **monitoring system** high-level objectives are

1) to detect future new hot spots,
2) to monitor and assess hot spots,
3) to assess emission changes, as expected from the NDCs
4) to assess the emissions trends (change in stocktake with 5 year timesteps).

An integrated system comprising: satellite - in-situ – modelling -emission inventory components, for provision of timely input to policymakers

This leads to the following mission objective of the space component:

The CO_2 mission shall monitor anthropogenic CO_2 emissions using high spatial resolution imaging of total column CO_2

CO_2 Monitoring Task Force (CO_2-MTF)

Dedicated Task Force with:

- **Sub-task B** (lead by EC-GROW & EC-JRC):
  - Group of experts focusing on the end-to-end monit
  - Output: user requirements and initial high-level sys

- **Sub-task A** (lead by EC-GROW & ESA):
  - Group of experts focusing on the space component
  - Output: mission requirements document

Requirements (RQs) sequence:

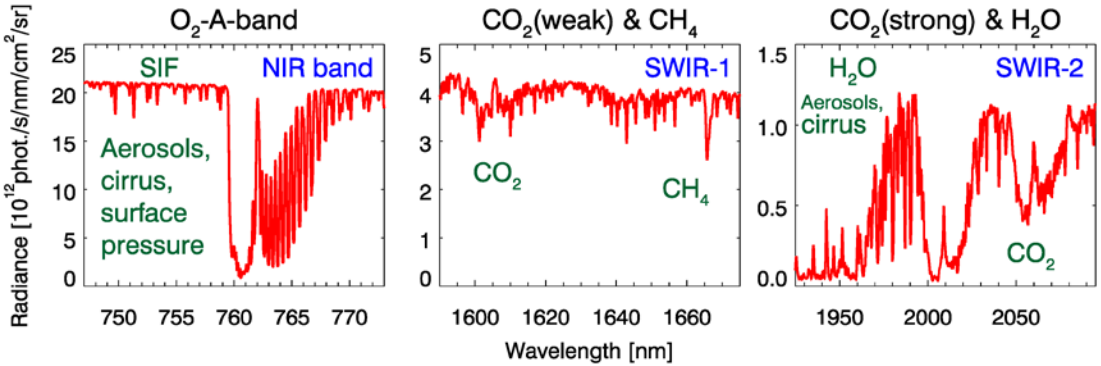
User RQs → product RQs → satellite product RQs → observation RQs → instrument

Policy → level-4 → level-2 → level-1 → level-0

Consolidating Requirements

Main open points:

- Complementary NO_2 and/or CO observations for attribution of anthropogenic emission sources → Y/N?
- Complementary aerosol/cloud observations for light path correction → Y/N?
- Temporal/spatial coverage → how many satellites?
- Required precision → SNR and spectral sizing?



ESA-initiated Support Studies

Support studies to consolidate the Mission Requirements Document (MRD)

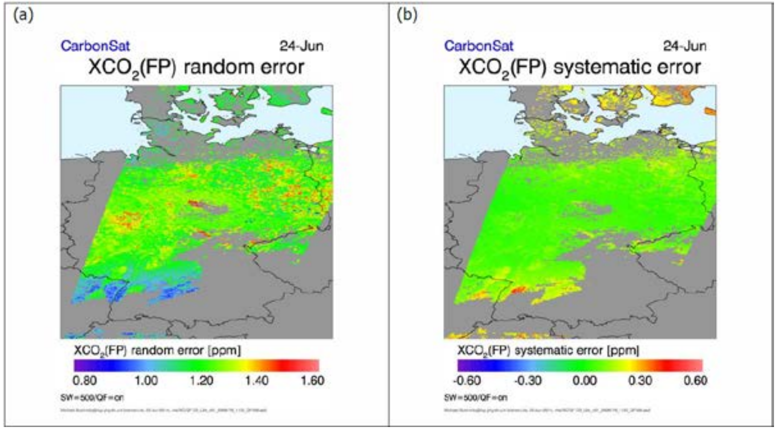
Study	Sys.	Prod.	Obs.	Ins.	Start	End	Prime
Study on CCFFDAS	XX	X			Q3 2017	Q1 2019	Inversion lab
Study on PMIF	X	XX			Q2 2017	Q4 2018	LSCE
Study on NO_2-CO	X	XX	XX		Q1 2017	Q2 2018	EMPA
Study on aerosol		XX	XX		Q2 2017	Q4 2018	SRON
Study on spectral sizing			XX	X	Q3 2016	Q2 2018	SRON
Study on E2ES			X	XX	Q4 2016	Q2 2018	IUP Bremen
Sys. & ins. pre-dev			X	XX	Q1 2016	Q3 2017	Various
ACADIA – airborne sys.		X	X	XX	Q3 2017	TBD	OHB

Study Example: PMIF

Poor Man’s Inversion Framework (**PMIF**)

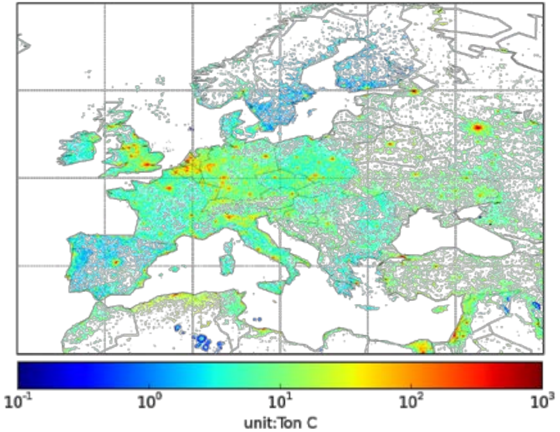
Key output: XCO_2 precision & temporal (L2) requirements for MRD

Method: assess detection thresholds and fraction within each country of fossil fuel CO_2 emissions, from power plants and cities, that would be detected by the space borne system



Credits: IUP

Credits: LSCE

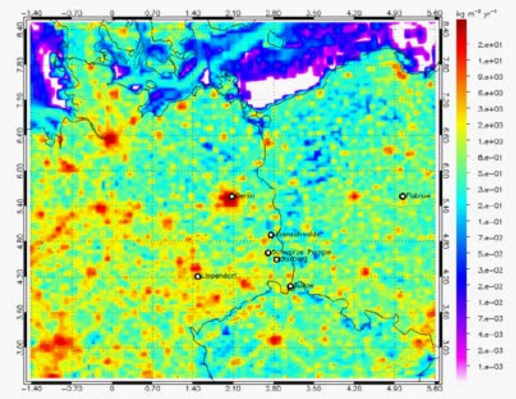


Study Example: SMARTCARB

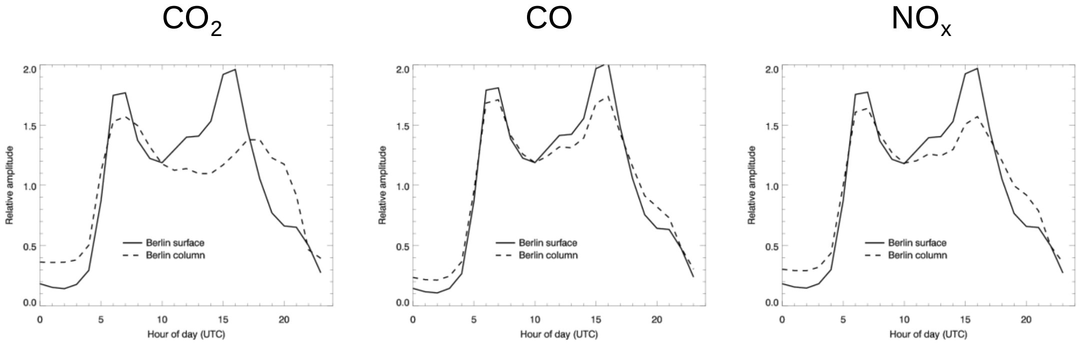
Satellite Measurements of Auxiliary Reactive Trace gases
for fossil fuel CARBon dioxide emission estimation (**SMARTCARB**)

Key output: possibly NO_2 and/or CO (L2) requirements for MRD

Method: exploit COSMO model with GPU implementation for GHG simulations to assess the added value of NO2 and CO observations to estimate and attribute anthropogenic CO_2 emissions.



Credits: EMPA

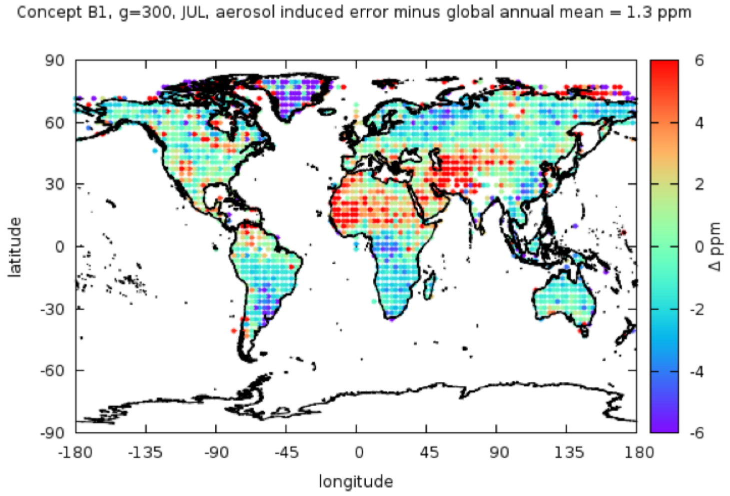


Study Example: AEROCARB

Study on use of aerosol information for estimating fossil fuel CO_2 emissions

Key output: possibly aerosol observational requirements for MRD

Method: WRF-CHEM model for aerosol and CO_2 simulations, and sub-sequent CO_2 flux inversion



Credits: SRON

CO_2 Monitoring – Observation Requirements

Primary Requirements (preliminary):

- XCO_2 precision: 0.5 – 0.7 ppm
- Systematic bias < 0.5ppm
- Spatial resolution ~4 km^2
- Continuously sampled swath with minimum swath width of 200km
- Revisit of ~3 days (poleward of 40 deg), over land & ocean (by a **constellation of N satellites**)
- Orbit equator crossing time 11:00 – 12:00hrs → to detect city emission peak, and to maximise coverage at high latitudes in all seasons

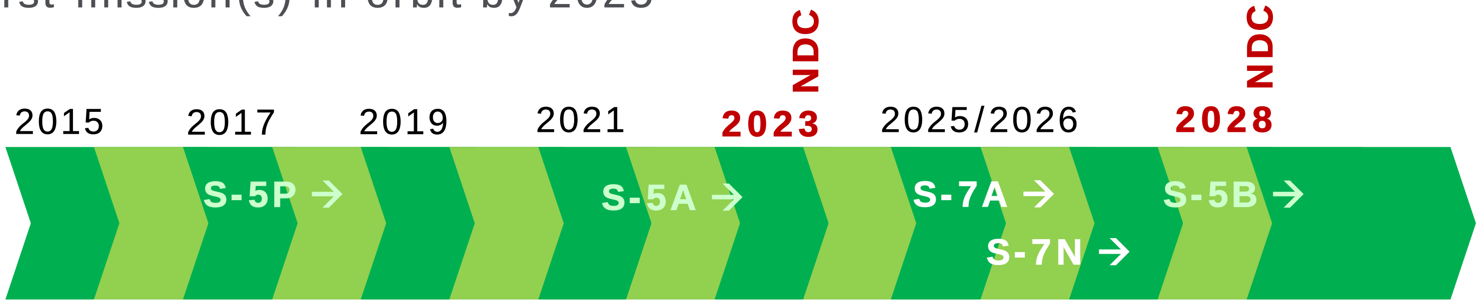
Band	Spectral range [nm]	Spectral resolution [nm]	SNR at reference radiance
NIR	747–773	0.1	400 - 600
SWIR-1	1590–1675	0.3	300 - 500
SWIR-2	1925–2095	0.55	200 - 400

* Radiometric accuracy better than 3%
* Relative radiometric accuracy < 0.5%

- Possibly additional observations of NO_2 (and/or CO) for separation of anthropogenic from biogenic fluxes
- Possibly specific aerosol/cloud observation capability (multi-angle polarimeter) for reducing scattering induced errors

Next steps – High level roadmap

- Draft MRD in Q3-2017
- Consolidated v1 MRD Q4-2017 ← Task B Report 1
- Start system studies Q1-2018
- Feedback from studies ↔ Task B Reports
- Consolidated v2 MRD Q2-2019 ← C-MIN 2019
- Start implementation Q1-2020
- First mission(s) in orbit by 2025



BACKUP SLIDES

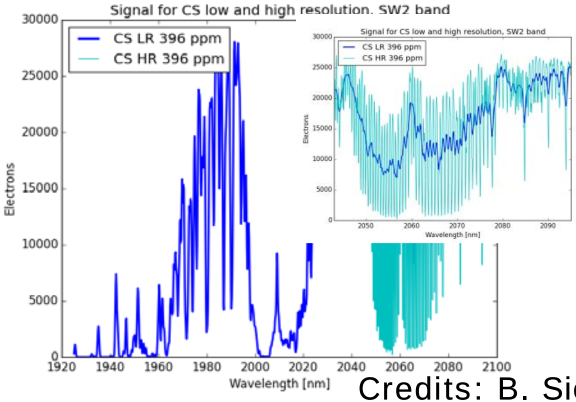
ESA study: Spectral Sizing Study

Study on assessing relative product accuracies for different spectral sizing

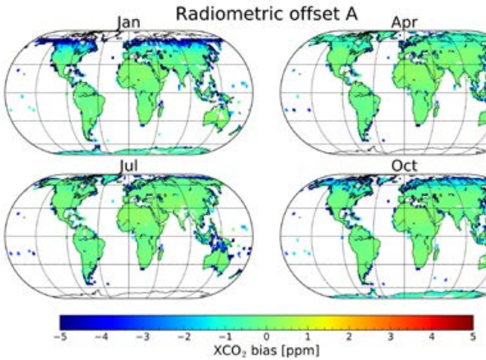
Key output: observational requirements (spectral sizing) for MRD

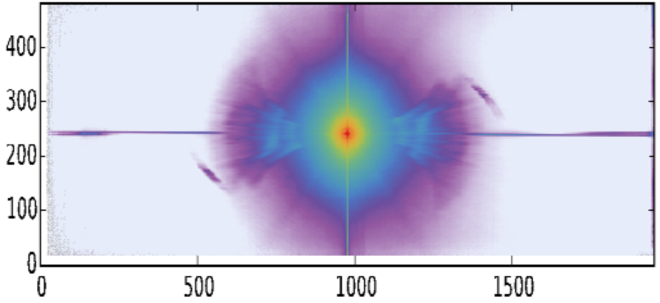
Method: use ensemble approach to assess the expected relative CO_2 product accuracies for different instrument spectral sizing points (spectral bandwidth, spectral resolution and SNR) assuming realistic retrieval and instrumental errors

Credits: SRON



Credits: B. Sierk





Credits: DLR