Quantifying localized carbon dioxide emissions from space: the CO2Image demonstrator

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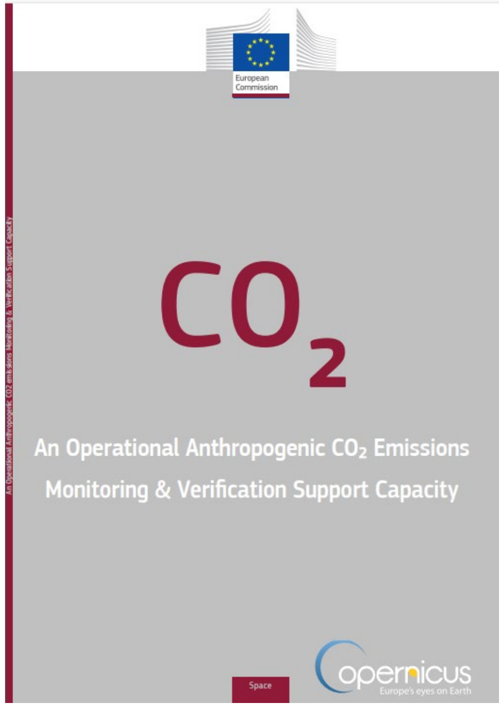
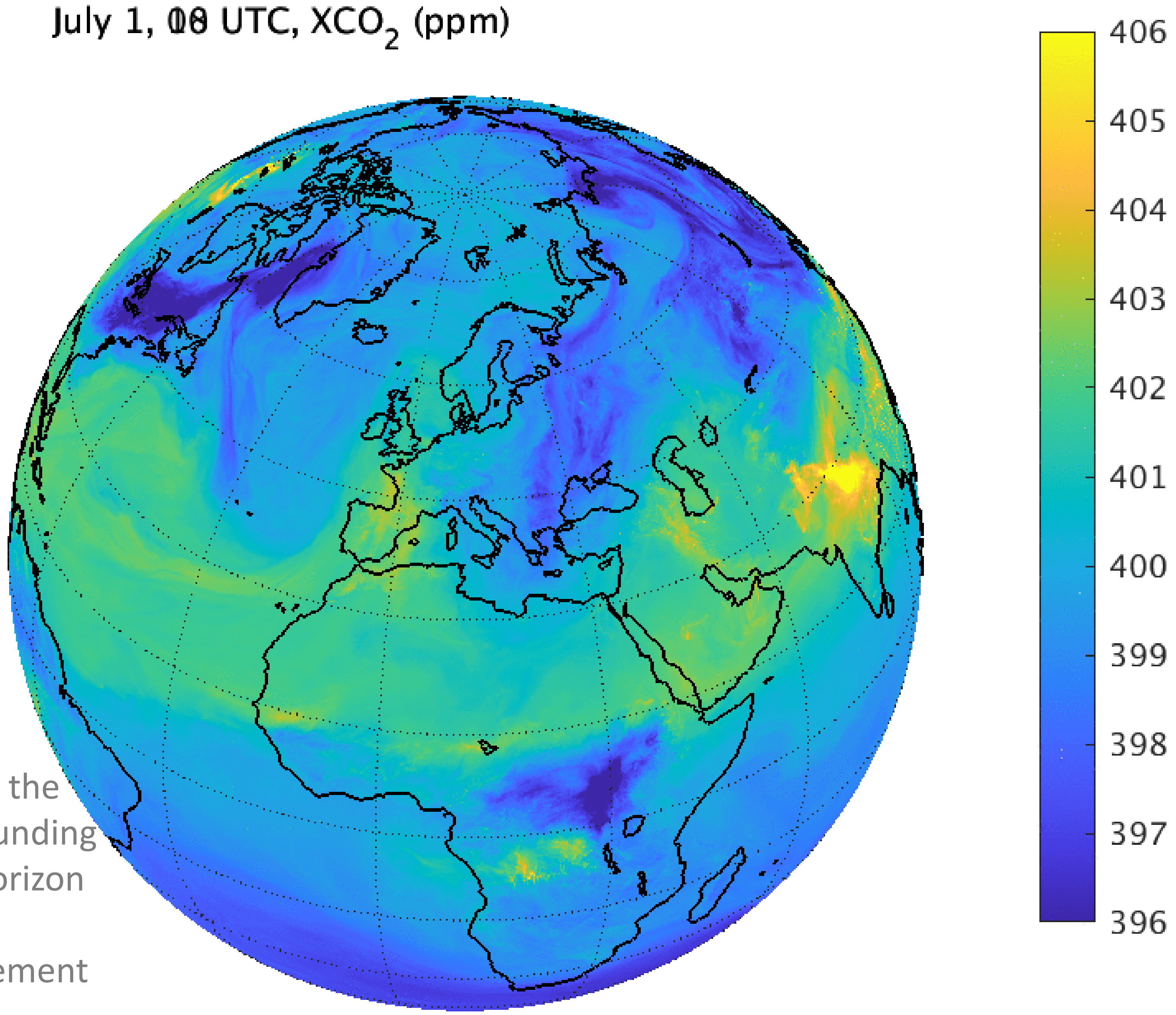
Understanding the problem

- We want to quantify anthropogenic emissions of CO_2 and CH_4 using atmospheric measurements
- The “easiest” problem is point source emissions of plumes, as described in the so-called “Red Report”:



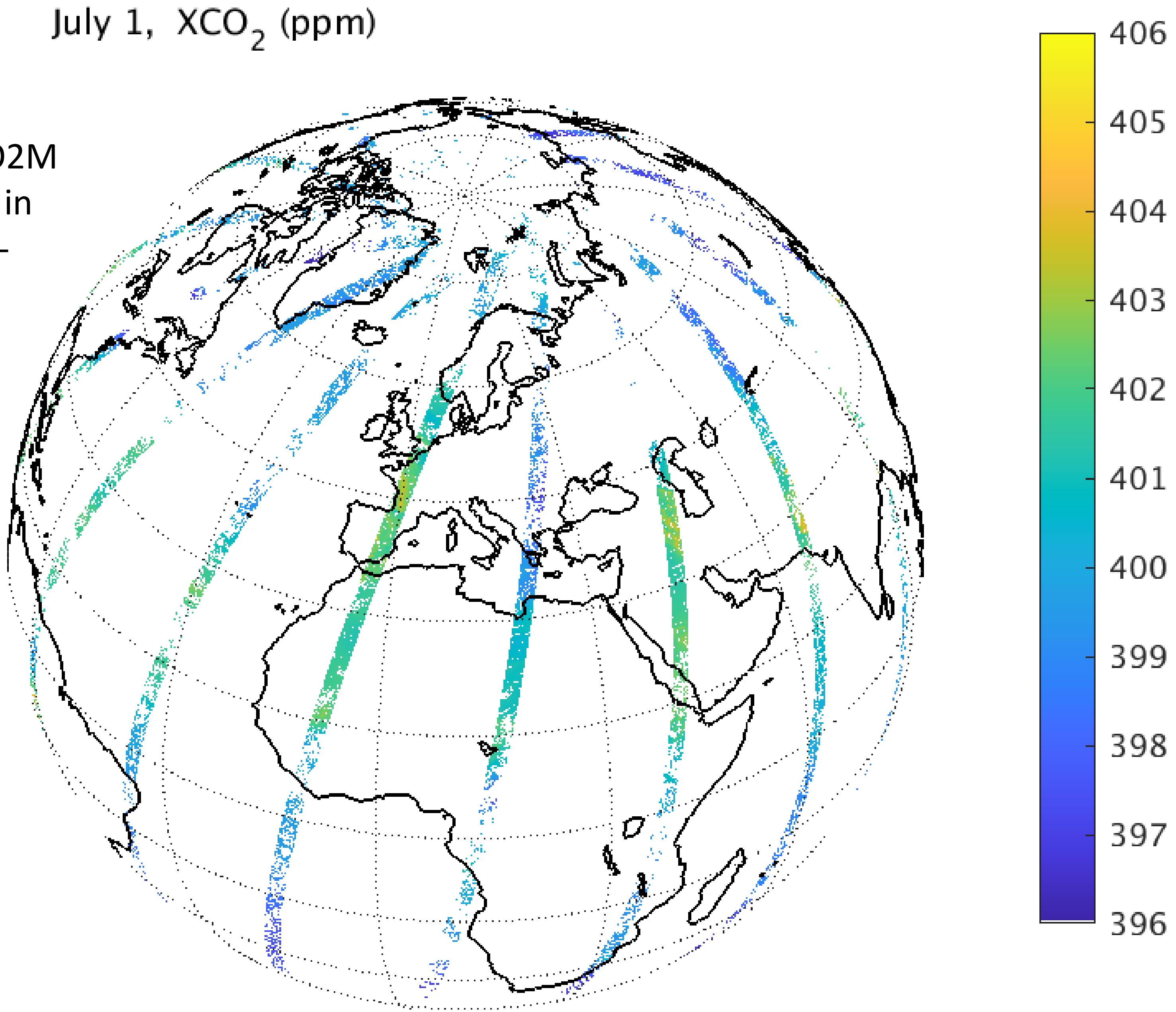
1. Detection of hot spot
2. Monitoring the emissions of the hot spot
3. Assessing emissions changes against local reduction targets (still focusing on the hot spot)
4. Assessing the national emissions and changes with 5-year time steps



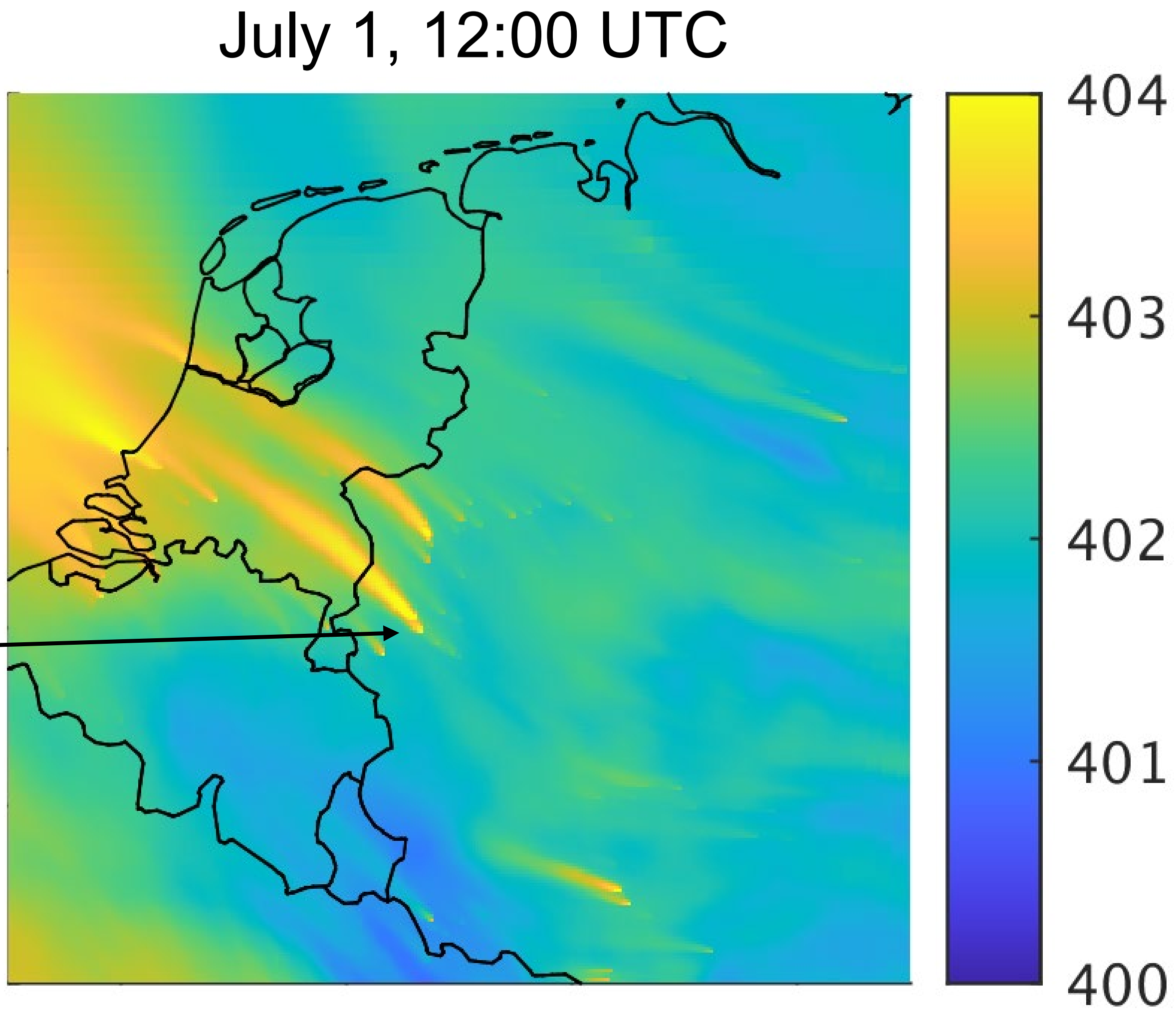
Data from the “nature run” of the CHE project, which received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 776186.

[Panareda et al., 2022]

Sampling for one CO2M satellite for one day in July (cloud- and SZA-filtered)



Already at 2-km resolution, large point sources are visible (with no clouds and perfect measurements)

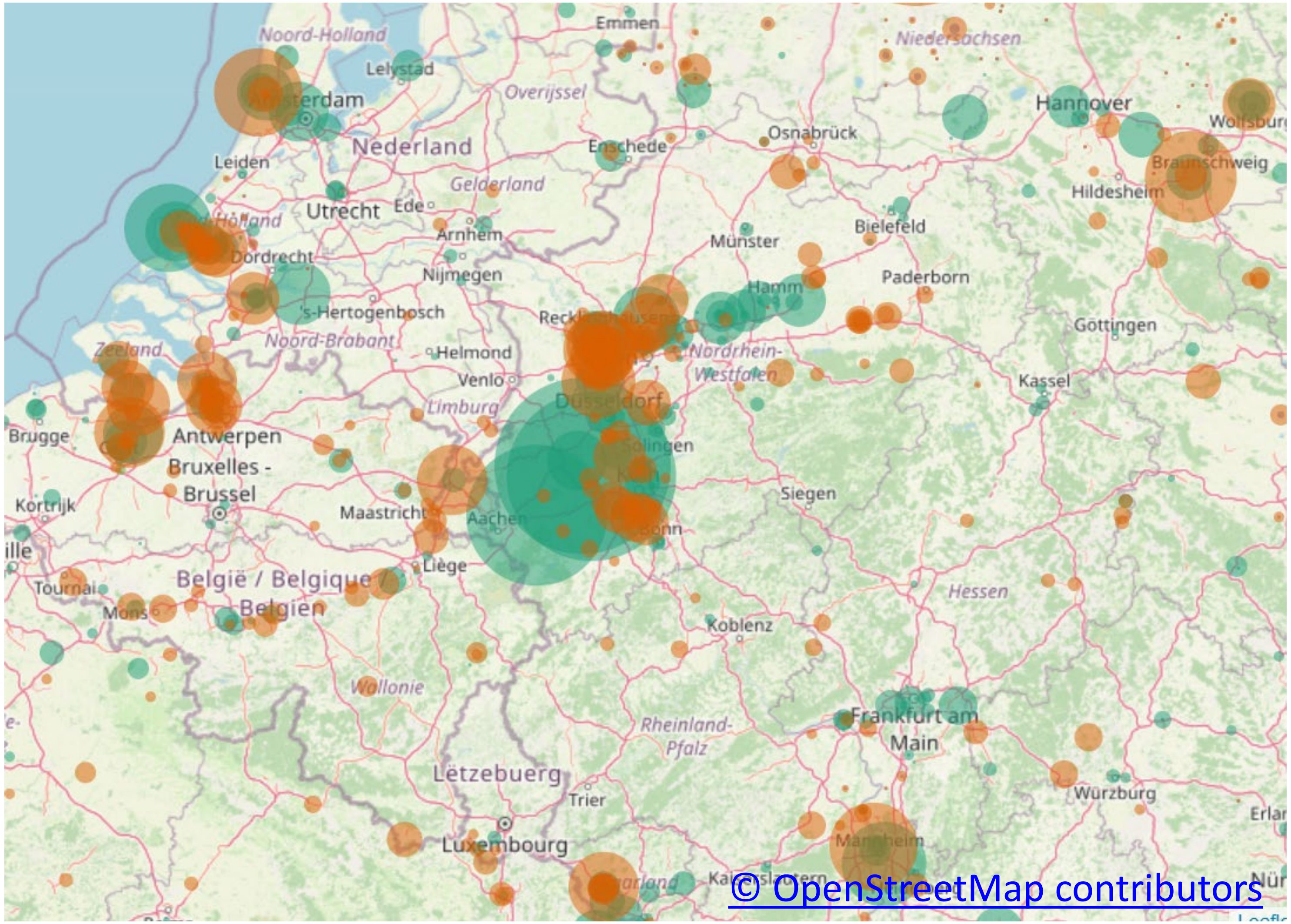


Power plants near Cologne with emissions of ~26 and 29 $MtCO_2$/yr

But there are plenty of smaller point sources as well…

Power generation
Industry

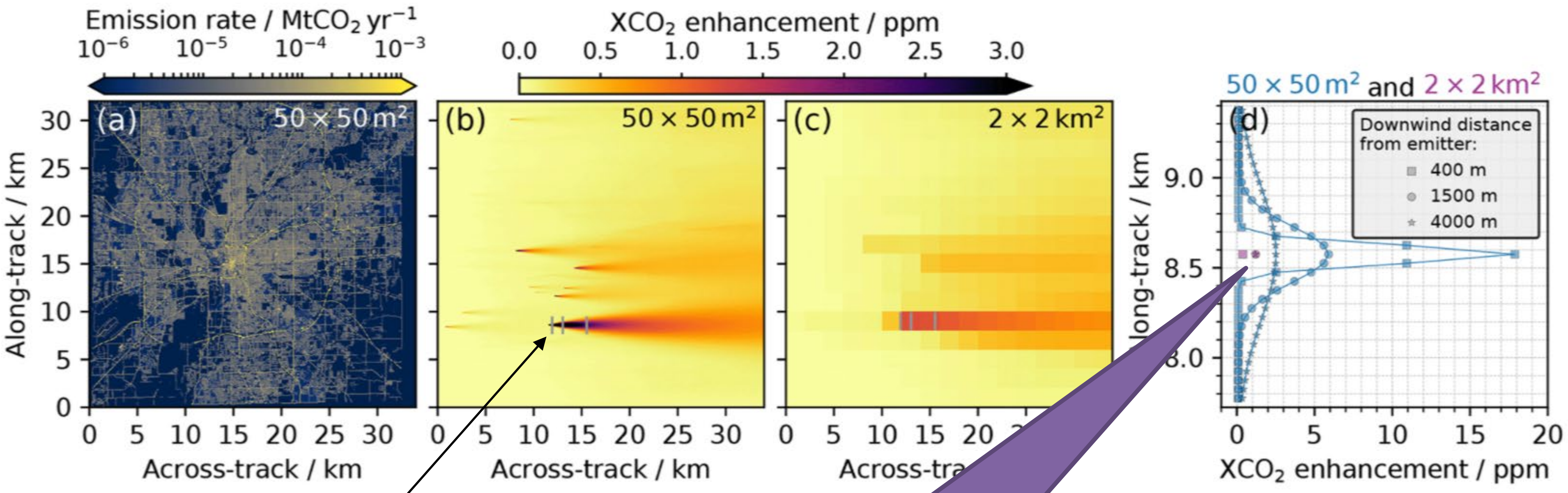
0.3 $MtCO_2$/yr
3 $MtCO_2$/yr
30 $MtCO_2$/yr



TNO_GHGco emissions

CO2Image targets this problem with a high-resolution approach

- Gaussian plumes simulated for the city of Indianapolis, at the resolution of CO2Image and CO2M (from Strandgren et al., AMT, 2020)

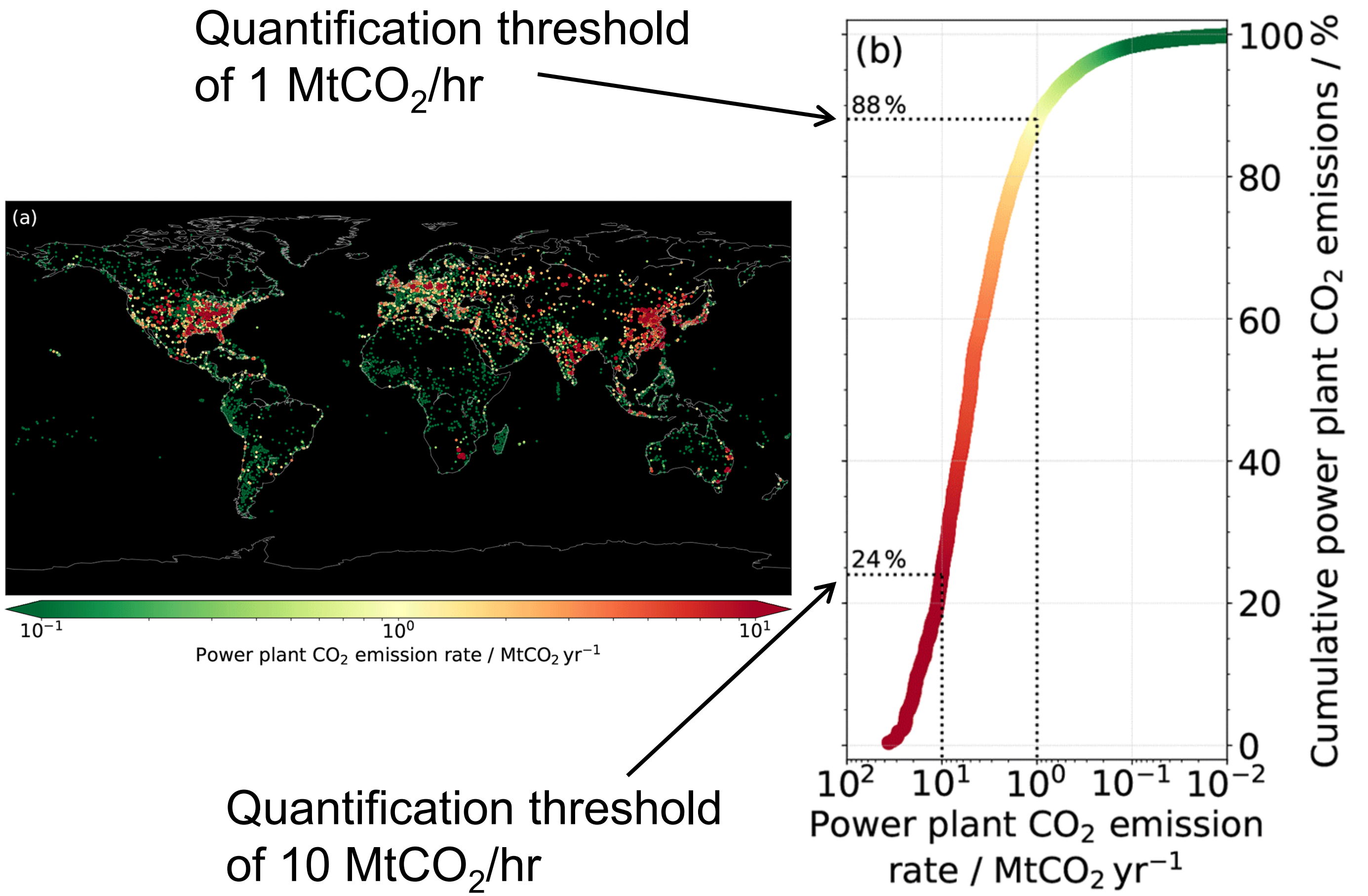


3.29 $MtCO_2$/yr

Leads to a very demanding measurement precision for CO2M!

Higher spatial resolution → quantification of smaller point sources

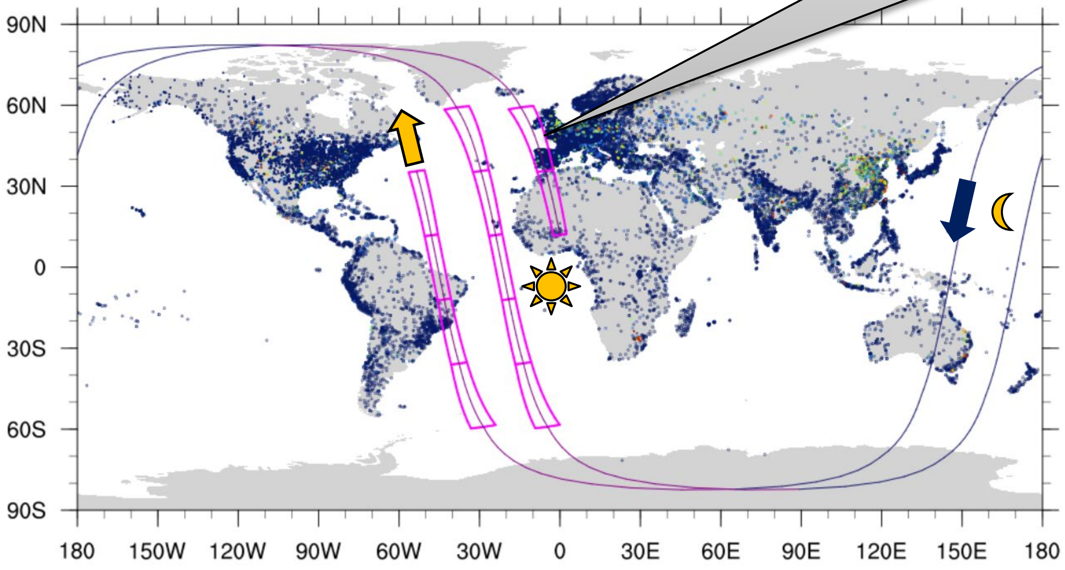
- A higher sensitivity (**down to 1 $MtCO_2$/year**) means that a higher proportion of point sources would be quantifiable based on remote sensing measurements:
  - A sensitivity threshold of > 10 $MtCO_2$/year could resolve 24% of emissions from coal-fired powerplants worldwide
  - A **sensitivity threshold of > 1 $MtCO_2$/year could resolve 88%** of emission from coal-fired powerplants worldwide



from [Strandgren et al., AMT, 2020]

Measurements in target mode

One ~50 km x 50 km scene can be chosen from each of these pink boxes



- Orbit altitude:
  575 km
  → Inclination = 97.6618°
  → Orbital period T = 1.60033 h
  → Orbits per day = 14.9969
  → Velocity = 7.57304 km/s
- Agility = ± 25°
  - along track
  - across track
- Integration time = 89 ms
- ≈ 5 targets per branch between 60°S & 60°N
  → time for repositioning

Benefits of fine (< 50 m) ground resolution:

- Enhanced concentration contrast
- Plume sampling by multiple ground pixels (plume detection via NO_2 is not required)
- Plume shape analysis for constraining turbulent dispersion

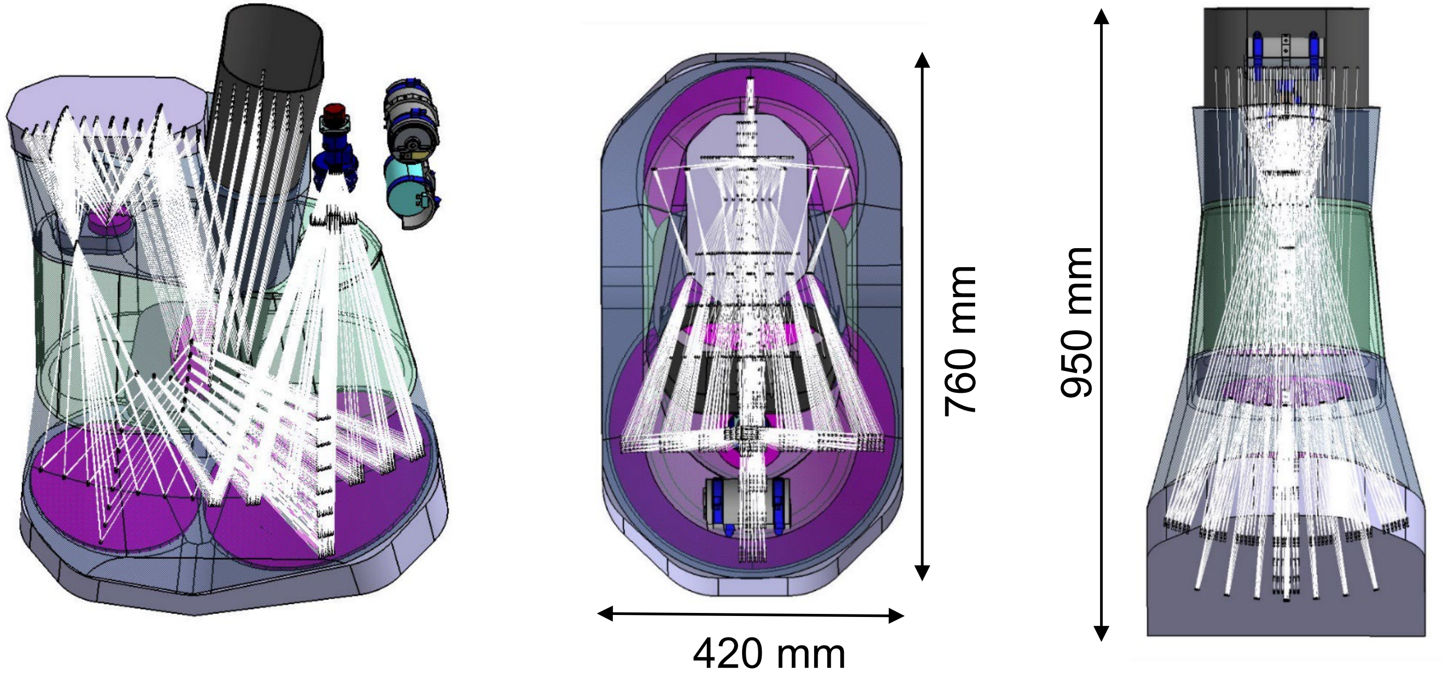
Drawbacks:

- Dense coverage on larger scales is not possible
- Operation restricted to “target mode”, focusing on a few 50 km x 50 km scenes per orbit

Thus: conceived of as a “magnifying glass” to **complement measurements from CO2M** and other survey missions.

COSIS Instrument description

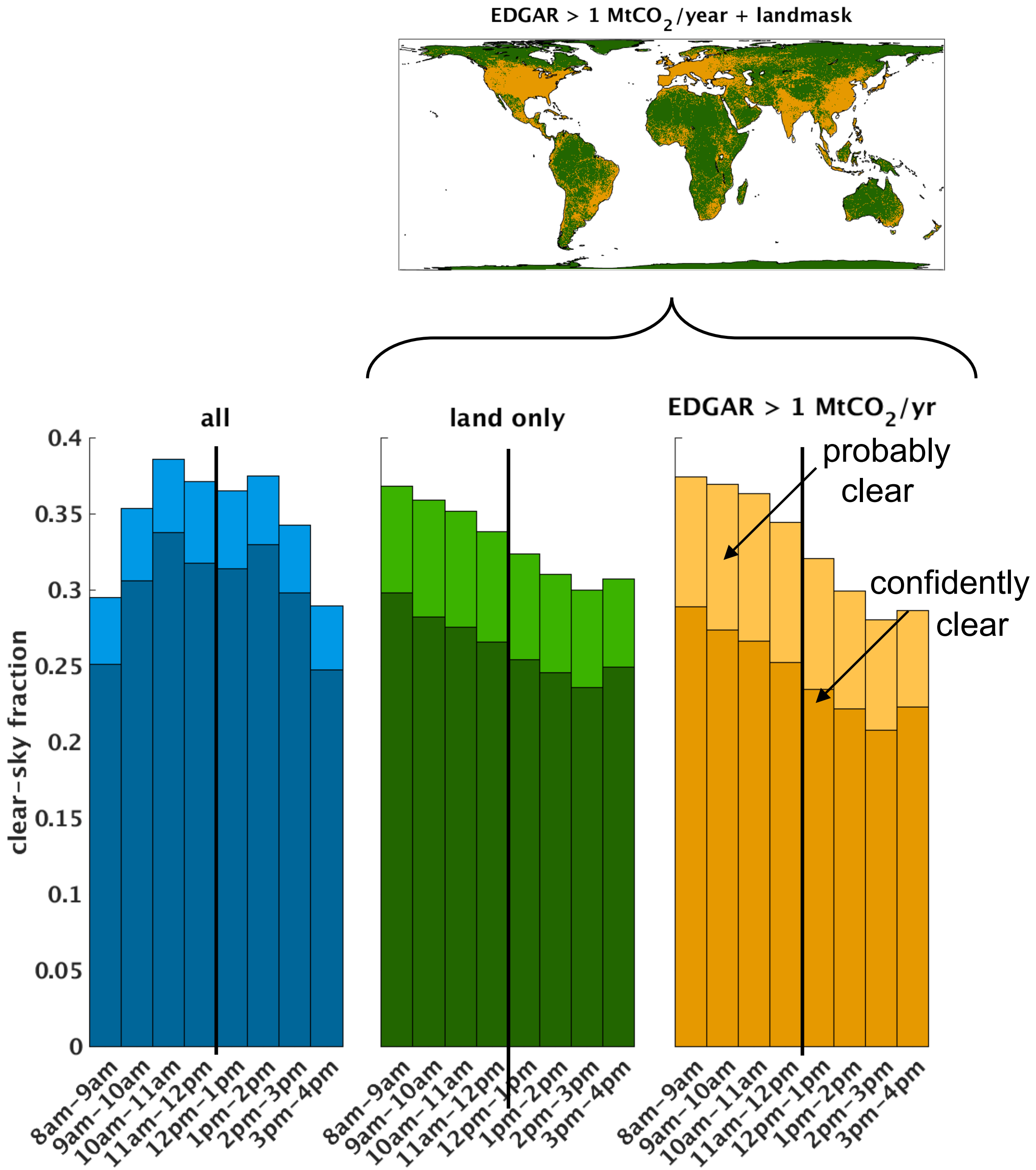
Mass	90 kg
Swath	50 km
Spatial resolution	50 m x 50 m
Spectral range	1982-2092 nm
FWHM (2.5 pix)	1.29 nm
Resolving power	1600
Aperture diameter	15.0 cm
f number	2.4
Optical efficiency (η)	0.48
Integration time	70 ms
Detector pixel area	900 μm^2
Quantum efficiency (Qe)	0.8 e^- $photon^{-1}$
Dark current	1.6 fA pix^{-1} s^{-1}
Readout noise	100 e^-
Quantization noise	40 e^-



- Measurement in SWIR-2 channel
- Spectral resolution optimized to maximize signal while minimizing correlations with surface spectral reflectance (see Wilzewski et al., AMT, 2020)
- Fast optics, large telescope, forward motion compensation

Overpass time

- A mid-morning overpass time of 10:30 is planned
- The morning is advantageous in terms of:
    - Less cloud cover
    - (slightly) lower mean winds
    - Sufficient light



Marshall et al., in prep.

Overpass time

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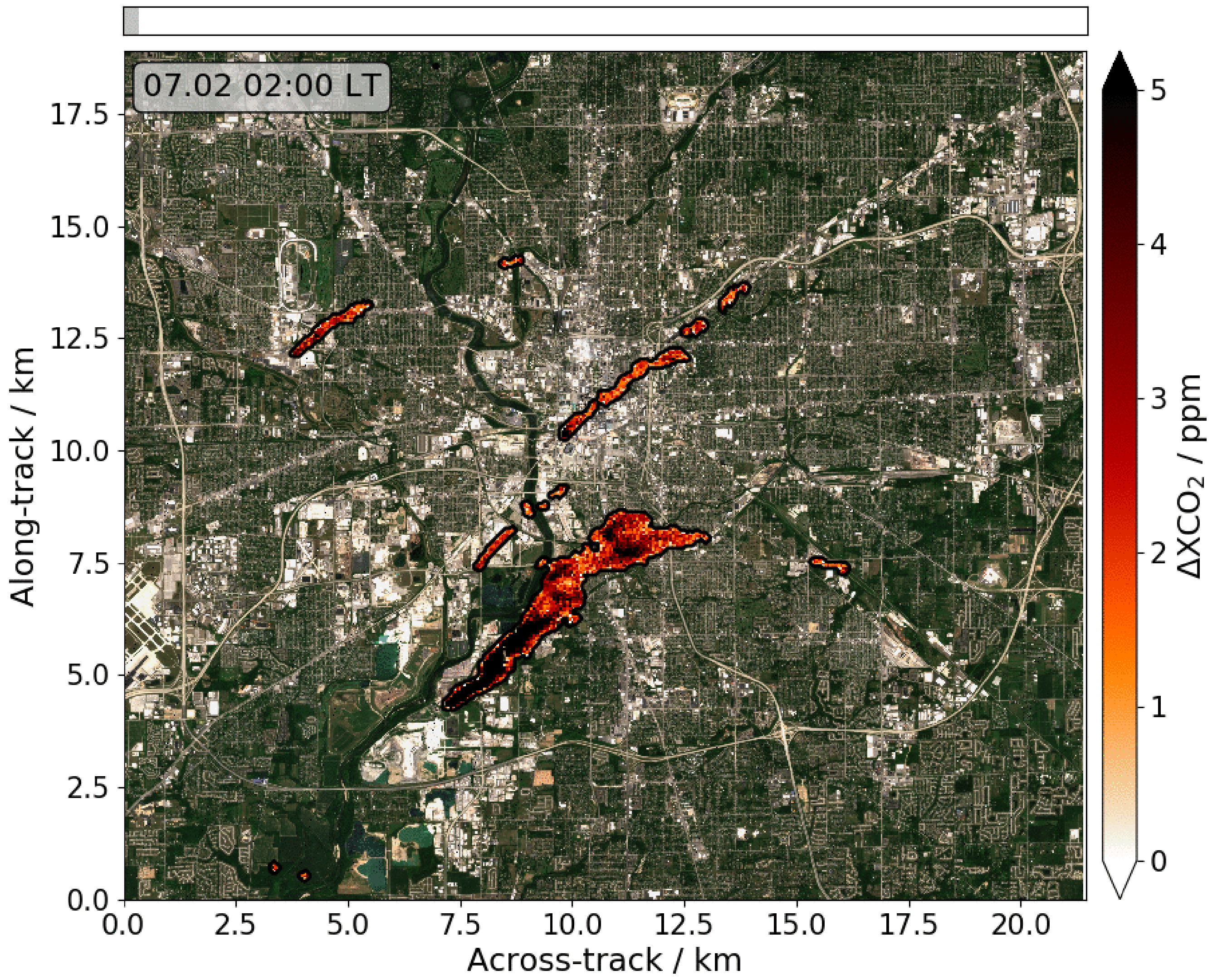

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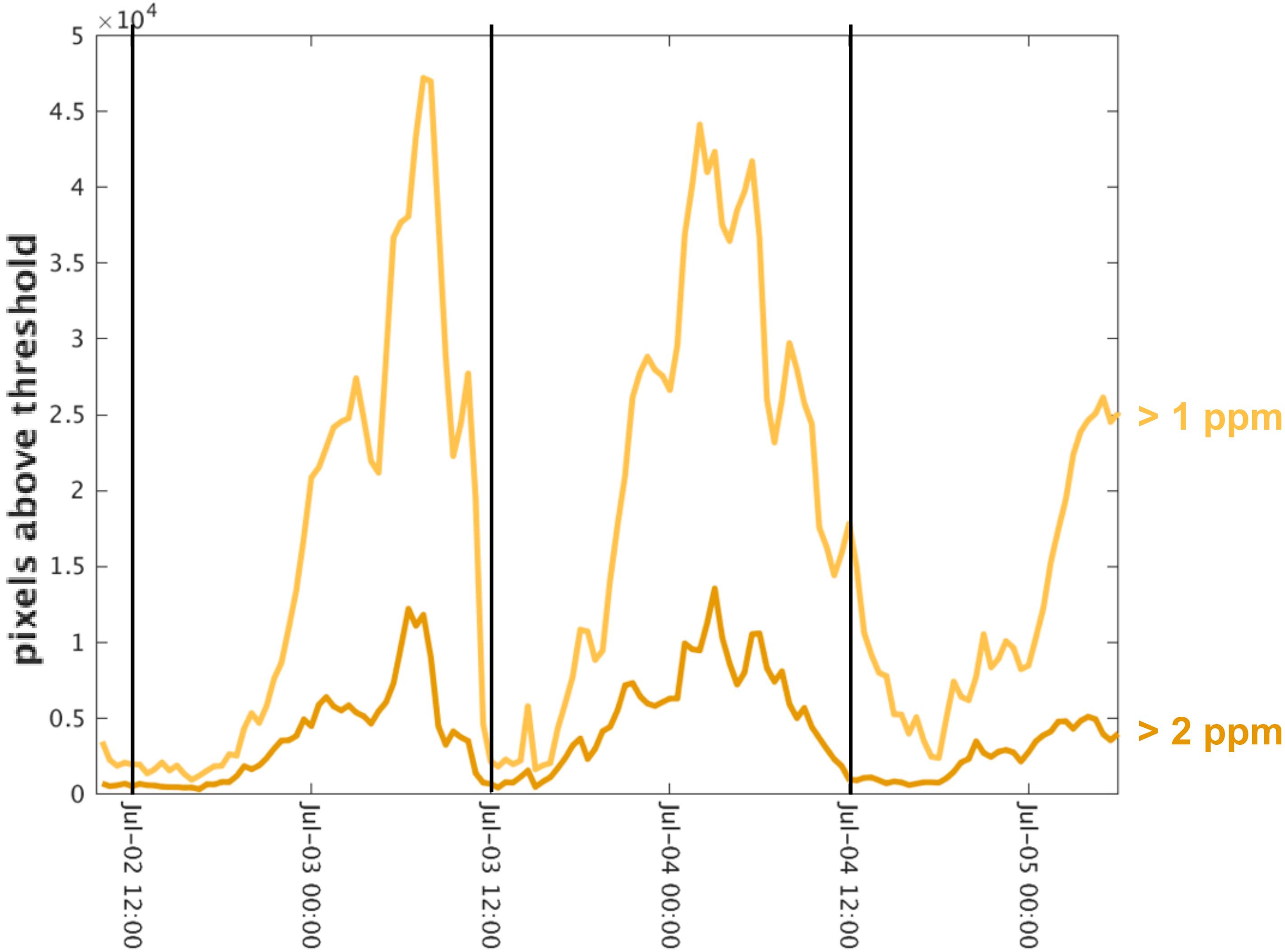
True for turbulent scenes on the scale of 10s of meters – at the kilometer scale this is less critical!



Marshall et al., in prep.

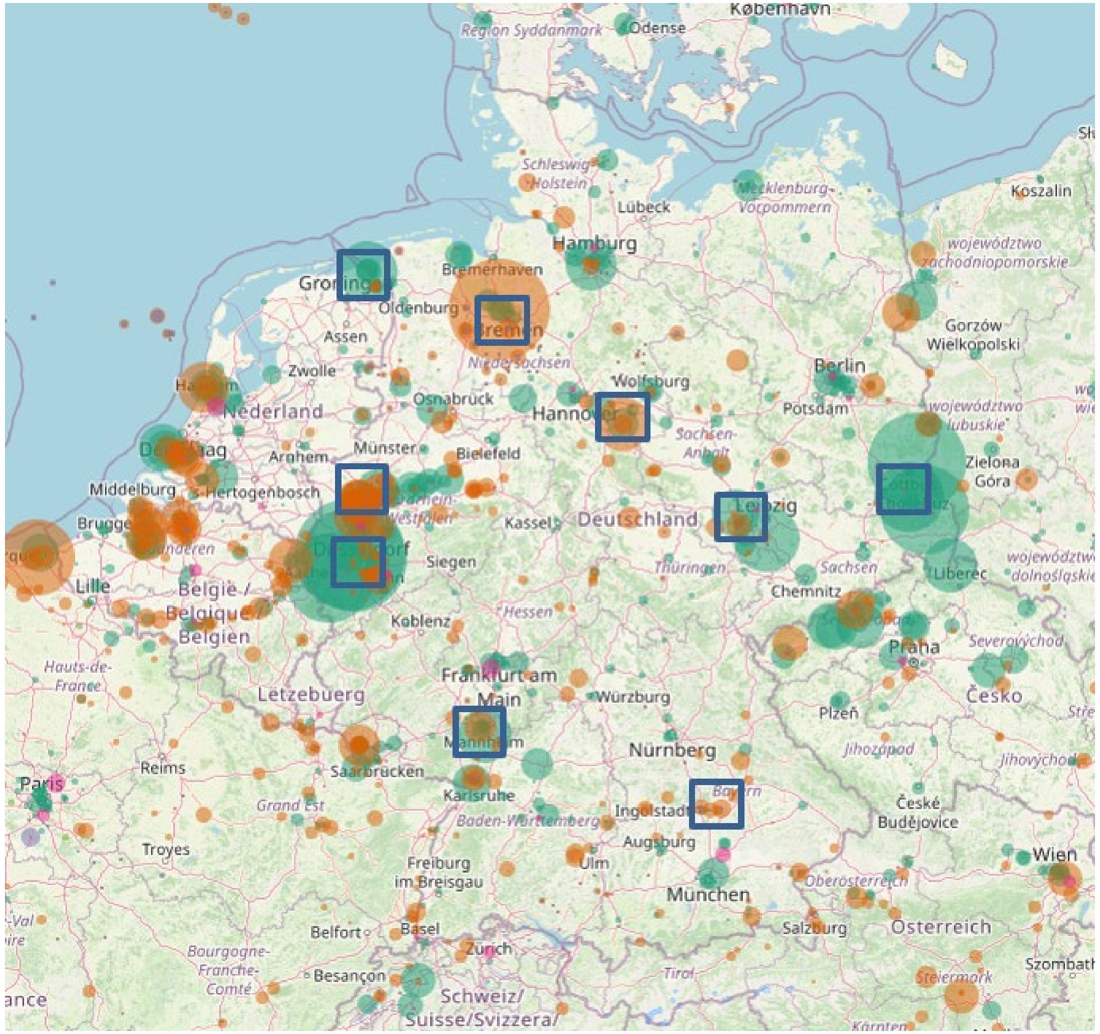
Ongoing work: development and testing of AI-based plume detection and emission estimation methods

- Further developing MethaNet approach developed by Jongaramrungruang et al. (2022), a CNN-based algorithm to deduce emissions with no information about wind speed provided (!)

- Training with less generic LES scenes

- Adapting to the scales relevant for our problem

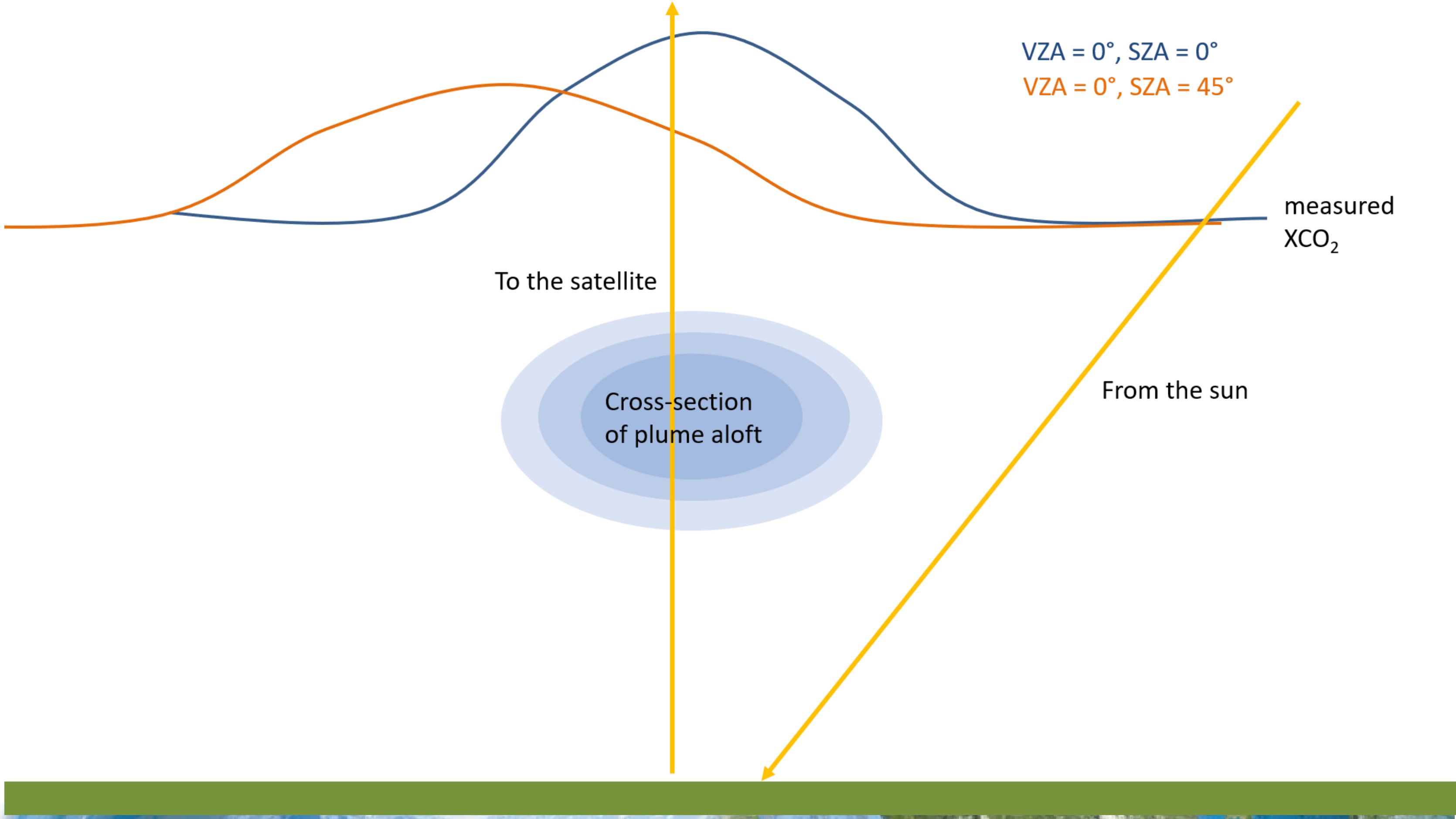
- Considering impact of 3D plume geometry…



DLR

Ongoing work: analyzing the importance of non-nadir geometry

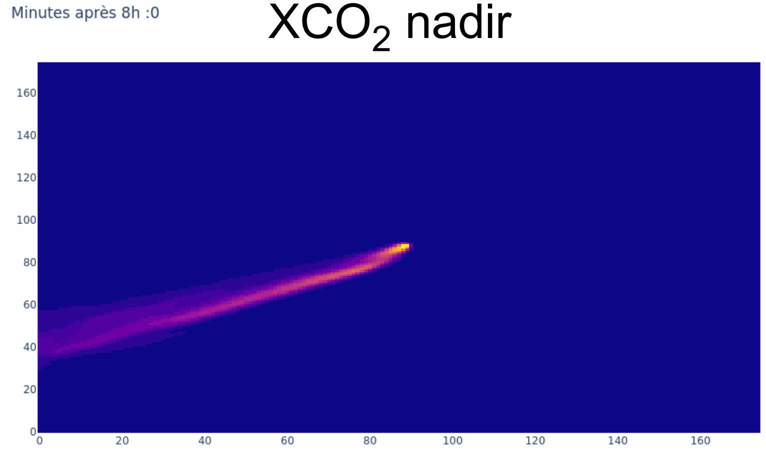
- Usually nadir geometry is assumed when interpreting retrieved L2 data
- When the pixel scale is much smaller than the troposphere height, this can break down
- Especially true for elevated plumes (like those from power plants)
- This can result in horizontal smearing and/or displacement of the plume compared to the nadir case



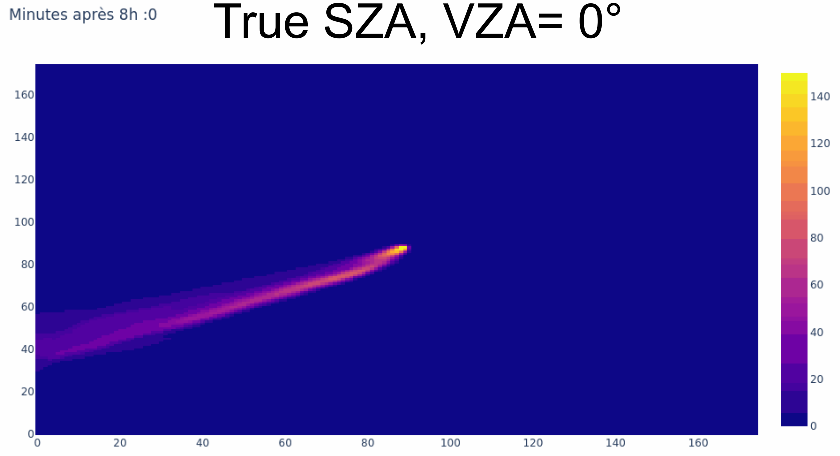
Ongoing work: analyzing the importance of non-nadir geometry

- Example using WRF simulation of Jänschwalde at 200-m resolution
- Source: 24 MtCO2/yr
- May 21, 2018, 8:00-16:00 UTC

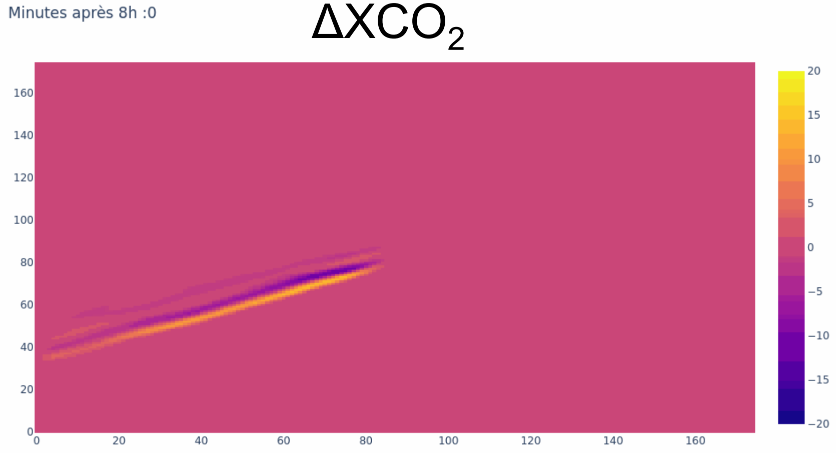
XCO_2 nadir



True SZA, VZA= 0°



ΔXCO_2

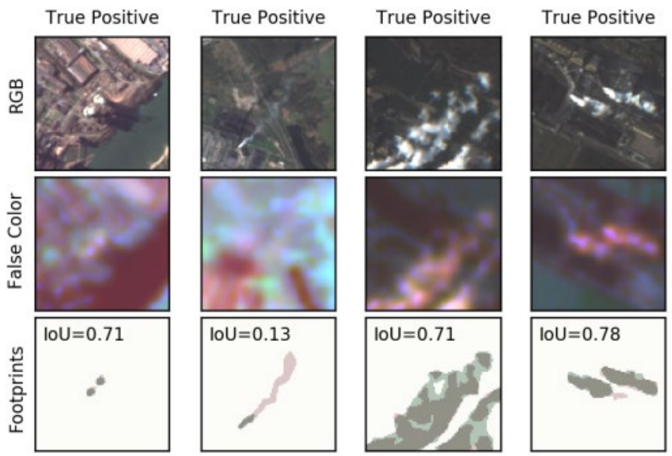


From Nicolas Tufel: submitted to IWGGMS

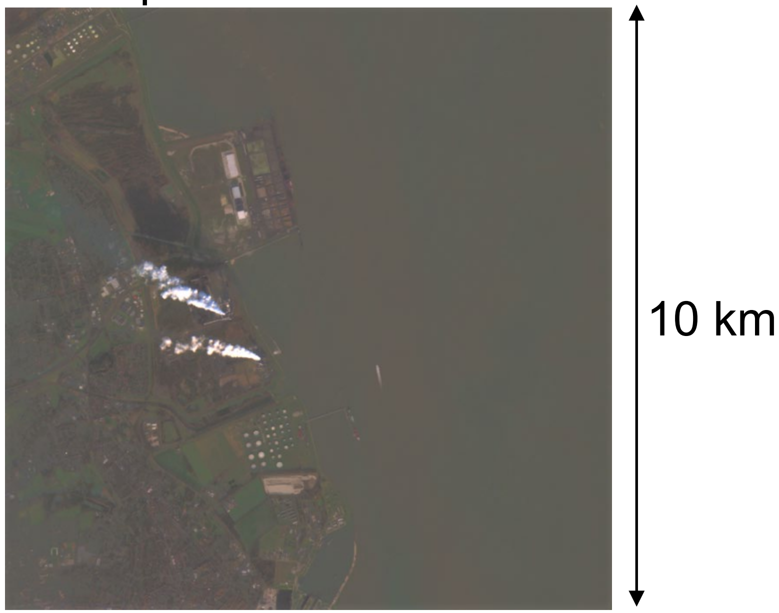
Simulations from Wolff et al., 2021

Ongoing work: compiling statistics about the frequency and extent of “smoke plumes” near point sources using Sentinel-2 data

- Applying identification and masking code developed by Mommert et al. (2020)
- Relevant for developing sampling strategy



Example: Wilhelmshafen

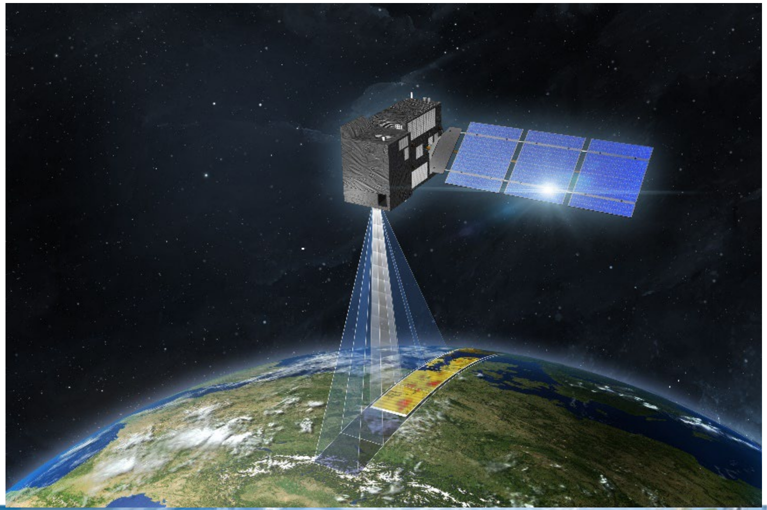


from Apolline Riet

DLR

Conclusions

- CO2Image will provide high-resolution measurements of XCO_2 to quantify emissions from point sources > 1 $MtCO_2$/yr, and detect smaller sources (> 0.3 $MtCO_2$/yr)
- Complementary to global survey missions such as CO2M
- Public mission providing public, transparent data
- Planned launch in 2026
- (we can also measure methane)



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