Assessment of the optimal operating point for a high resolution XCO2 imager dedicated to the monitoring of 0.1 to 15.0 $MtC.yr^{-1}$ sources

F. Graziosi [1,2], G. Broquet [1], P. Kumar [1], P. Ciais [1], D. Simeoni [3]

[1] Laboratoire des Sciences du Climat et de l'Environnement, LSCE/IPSL, CEA-CNRS-UVSQ, Université Paris-Saclay, 91198 Gif-sur-Yvette, France
[2] European Commission Joint Research Centre, Ispra (Va), Italy
[3] Thales Alenia Space, 06150 La Bocca, France

TRACE - TRAcking Carbon Emissions
Programme Chaires Industrielles ANR 2017

IWGGMS-18, 12th July 2022

trace.lsce.ipsl.fr/

Context and objectives

- Study of a concept of **high-resolution** (100-300m) but **narrow swath XCO_2 spaceborne imager** by TAS (**Carbon-CGI**; Simeoni et al. ICSO & SPIE 2022)
  → **complementing the CO2M satellites** for the **monitoring of CO_2 anthropogenic emissions**

- Atmospheric inversion to provide indications on **the optimal trade-off** between **the Sounding Point Distance** (spatial resolution), **the Sounding Point Precision** (noise per pixel of image) **and the swath** (width of the images) i.e. the optimal **Auxiliary CO2M Instrument (ACI) observing system parameters**

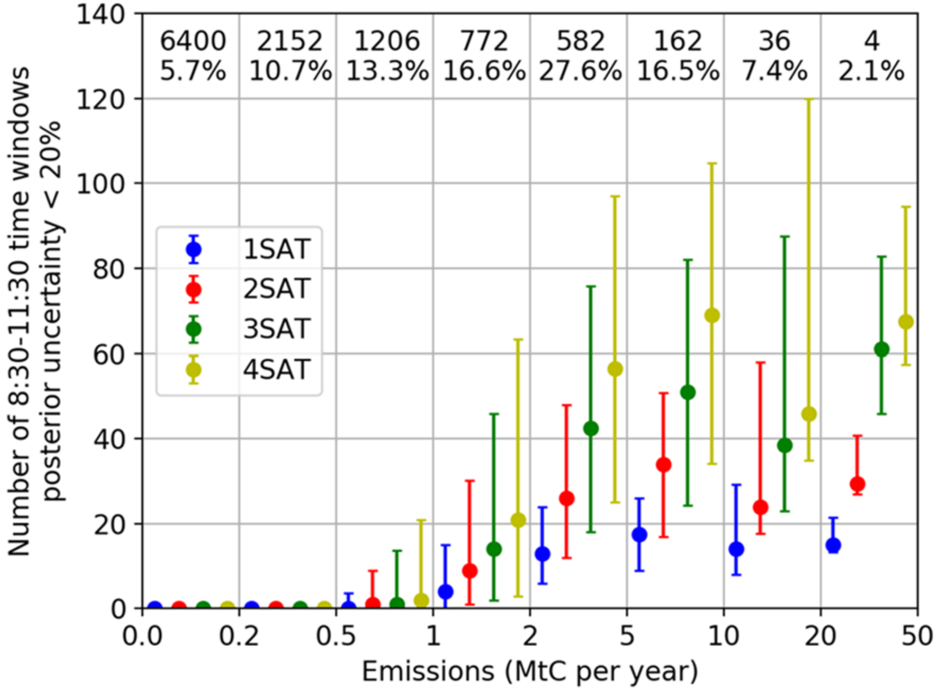
- Assumptions:

→ the ACI should target **individual sources (cities, industrial plants) whose emission rates** (whose plume amplitudes) **are too small for CO2M**

→ the best option corresponds to the quantification of sources not caught by CO2M, which together represent **the largest share of the global emissions**

→ Difficulties to quantify sources whose extents are nearly the size of the images (problem of characterization of signal in the plume vs. background)

→ We can focus on the **capability to estimate the emissions of a source over few hours before an image is taken in academic atmospheric and observation conditions**



Number of days for which atmospheric inversions using CO2M XCO_2 data can provide estimates of city or industrial plant emissions over 3-h with less than 20% uncertainty
Distribution of the results in bins of cities/plants according to their total emissions.
Lespinas et al., 2020, CBM (ESA-PMIF)

General principles

- **Inversions to study the ability to quantify a source over the few hours before a satellite image of its plume**
  - → locating the center of the source upwind but close to the center of the image (agility of ACI observing system)
  - → as a function of the ACI observing system parameters: **spatial resolution, precision and swath**
  - → **as a function of the source area and total emissions,** considering constant emissions
  - → for different academic atmospheric conditions (with different **wind speeds**), ignoring the cloud mask
  - → using a simple **statistical analytical inversion scheme** (projection of the information content and uncertainties from the observations and adding background uncertainties; no « prior » statistical knowledge on the emissions) and a **high resolution transport model**
- **Binning the sources potentially seen around the globe as a function of their extent and total emissions**
  - → assessing the share of global emissions represented by each bin
- **Assessing the share of global emissions covered by CO2M + ACI as a function of the ACI observing system parameters**
  - → Conclusion: identification of the optimal configuration

Analysis of the distribution of cities and industrial plants in terms of extent and total emissions

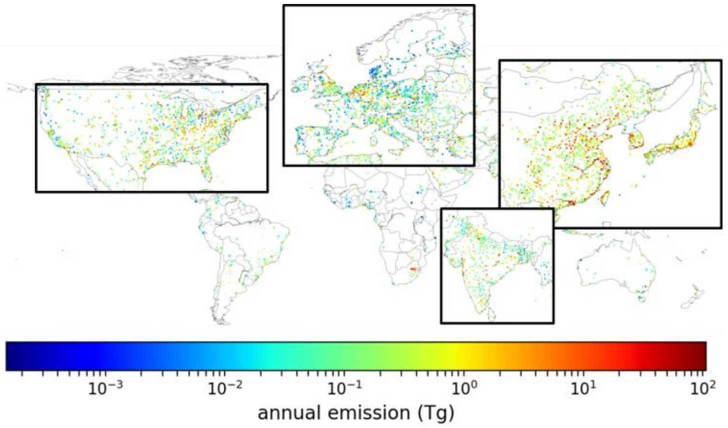
Based on the ESA-PMIF study: see Wang et al. 2019, ESSD

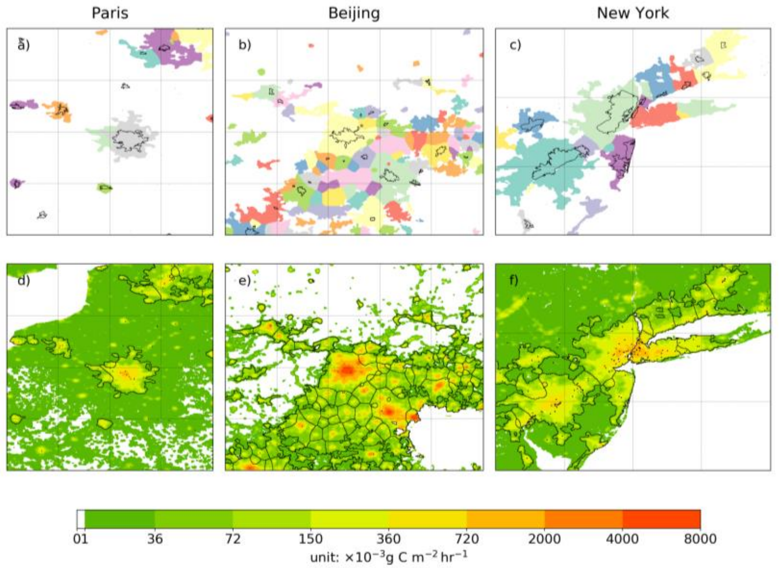
→ decomposition of the **ODIAC global 1 km res.** inventory of the annual emissions

→ extraction of the large point sources, identification of the emissions clusters

→ **~11000 « clumps » (~70% of the global emissions)** extracted

Inversions → which bins of sources can be targeted by the different ACI configs





Observation configurations

Observation scenario	Swath [km]	Spatial res. [m]	Noise [ppm]
CO2M	240	2000	0.7
CarbonCGI_ACI1_100	50	100	2
CarbonCGI_ACI1_200	50	200	1.1
CarbonCGI_ACI1_300	50	300	0.8
CarbonCGI_ACI2_100	30	120	0.9
CarbonCGI_ACI2_200	50	200	0.6
CarbonCGI_ACI2_300	50	300	0.5
IOD_50_600	50	600	1.9
IOD_112_800	112	800	3
IOD_240_1600	240	1600	2

- Precision performance computed in the frame of ESA CarbonCGI study (Simeoni et al., ICSO Dubrovnik 2022 & SPIE Berlin 2022)
- CarbonCGI_ACIx_y00 : CarbonCGI with x (1 to 2) focal plane(s) obtained for a pixel size of y hundred (s) meters.
- IOD_x0_y00 : In Orbit Demonstrator with a pixel size of y hundred (s) meters and a swath of x0 km

High resolution transport modeling

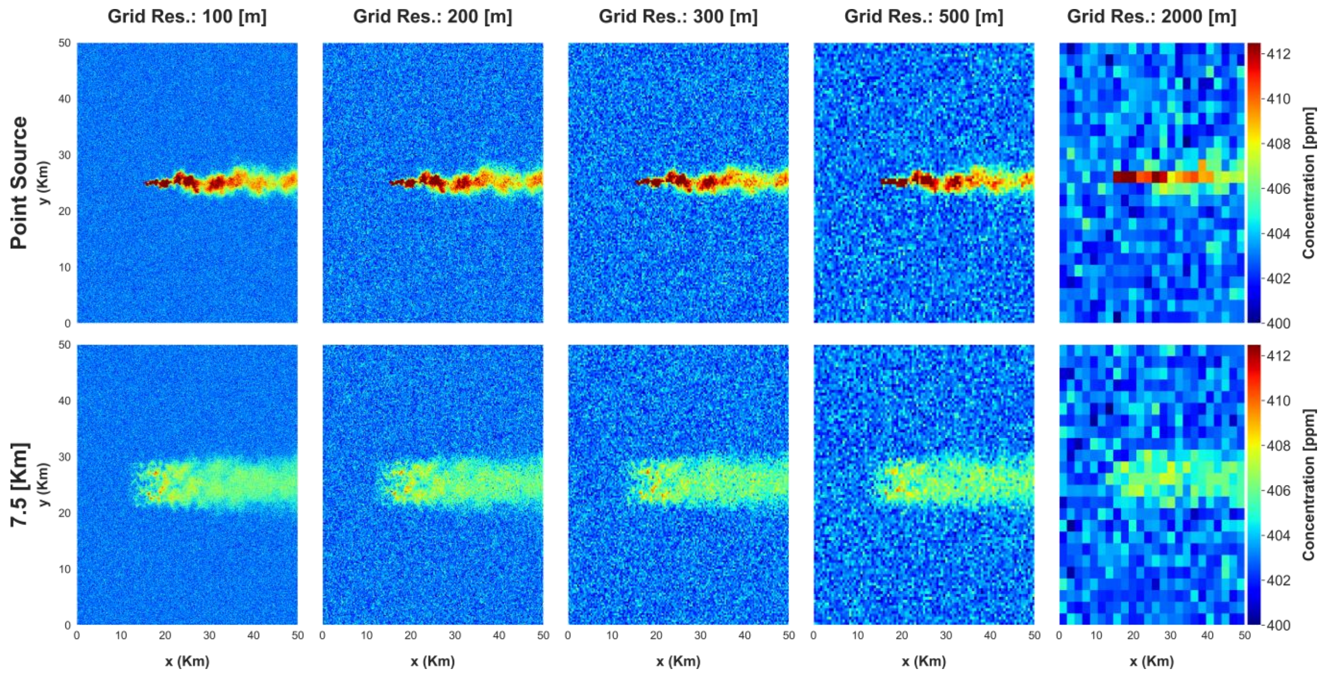
Simulations of plumes from sources with 6 widths and 7 emission rates in academic conditions

→ **with the Large Eddy Simulation (LES) model Palm** (with turbulence) producing realistic sharp gradients of XCO_2

- **Computation domains :** 50 Km or 240 Km
- **Model spatial resolutions :** 100 m or 200 m
- **Source rate** : ranging from 0.1 to 15 MtC/yr
- **Effective mixed layer wind direction** : 270° (from West)
- **Effective mixed layer wind speed** : ranging from 3 to 14 ms^{-1}

Sampling the XCO2 plume at the different spatial resolutions, with the different swaths and adding the instrumental noise corresponding to the ACI configurations (+ background error)

3 Mt C yr^{-1} sources ; 3 ppm instrumental noise at the sampling resolution



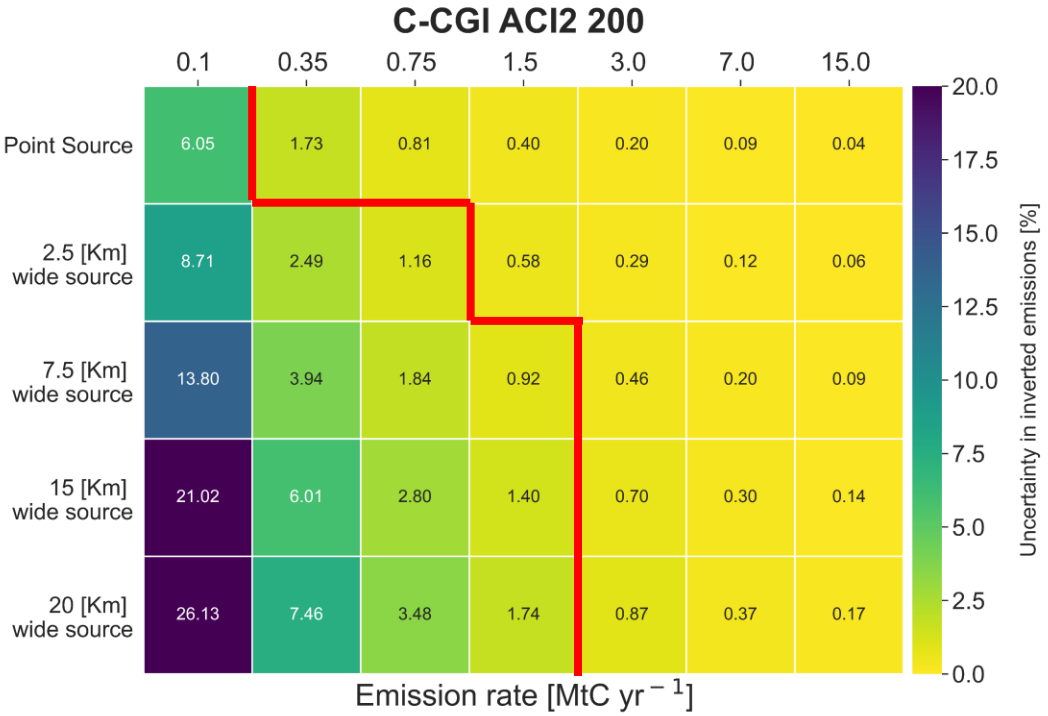
Simulation of the observations:

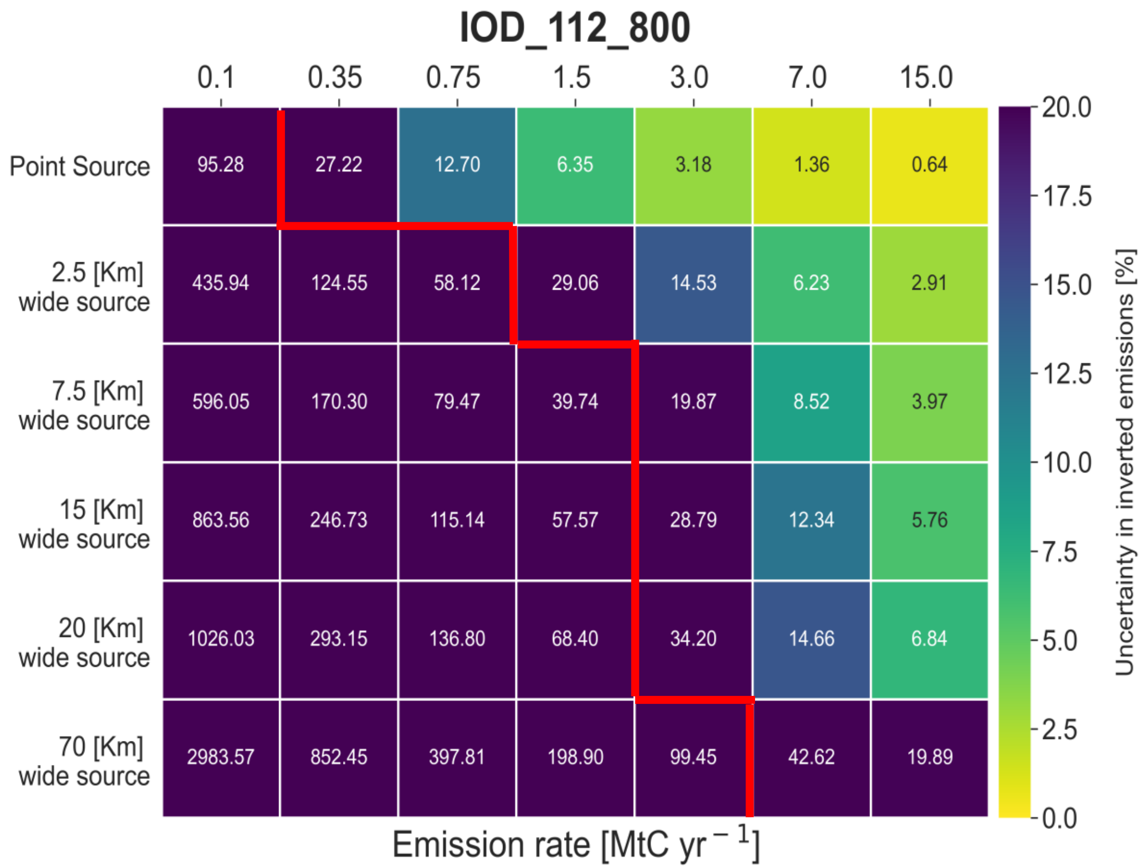
- **XCO2 field extracted from the model at the observation time**
- **400 pm homogeneous background**
- **center of the source located 15/50 km upwind to the center of the swath**

Uncertainties in emissions estimates as a function of the source sizes and rates

Results for effective wind speed of 3.3 [m/s]

Red lines delimitate the clumps covered by the CO2M configuration with uncertainty < 20 %



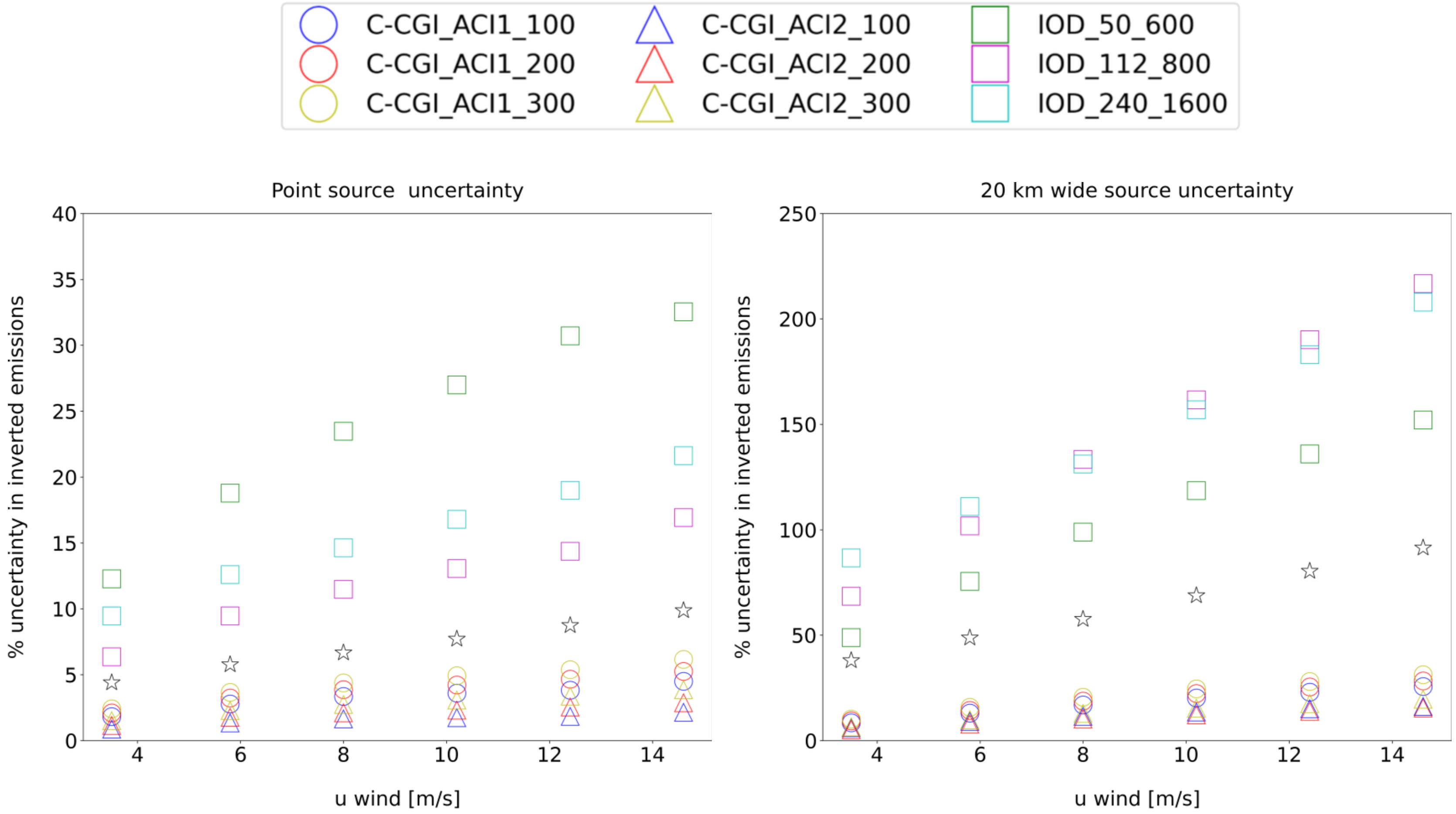


Uncertainties as a function of the wind speed

Results for 1.5 MtC/yr point sources and 20-km wide sources

→ Lowest uncertainties from CarbonCGI-ACI2 configurations

Observation scenario	Swath [km]	Spatial res. [m]	Noise [ppm]
CO2M	240	2000	0.7
C-CGI_ACI1_100	50	100	2
C-CGI_ACI1_200	50	200	1.1
C-CGI_ACI1_300	50	300	0.8
C-CGI_ACI2_120	30	120	0.9
C-CGI_ACI2_200	50	200	0.6
C-CGI_ACI1_300	50	300	0.5
IOD_50_600	50	600	1.9
IOD_112_800	112	800	3
IOD_240_1600	240	1600	2

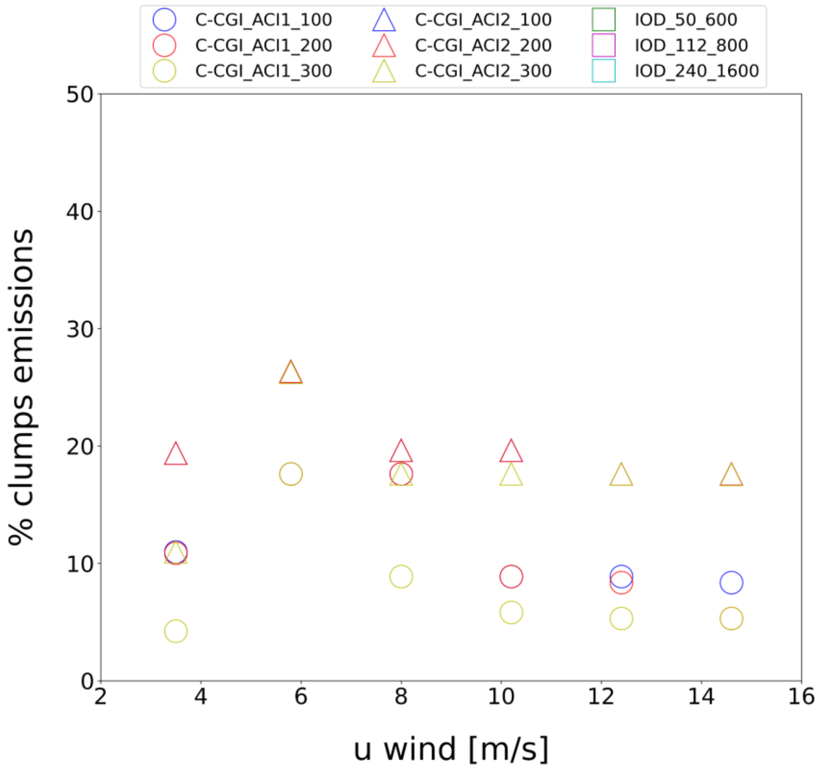


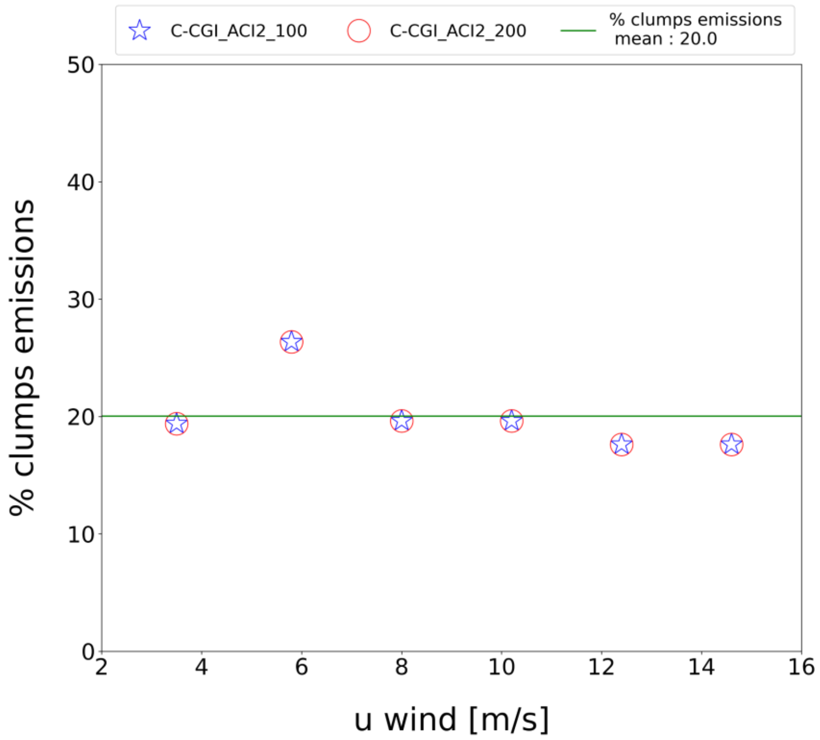
Fraction of clump emissions covered by the ACI configurations in complement to CO2M

Best coverage: from CarbonCGI-ACI2 configurations

Observation scenario	Swath [km]	Spatial res. [m]	Noise [ppm]
CO2M	240	2000	0.7
C-CGI_ACI1_100	50	100	2
C-CGI_ACI1_200	50	200	1.1
C-CGI_ACI1_300	50	300	0.8
C-CGI_ACI2_120	30	120	0.9
C-CGI_ACI2_200	50	200	0.6
C-CGI_ACI1_300	50	300	0.5
IOD_50_600	50	600	1.9
IOD_112_800	112	800	3
IOD_240_1600	240	1600	2

% clumps emissions potentially estimated with an uncertainty < 20% not covered by CO2M configuration
(total clump emissions ~72 % of the global fossil fuel CO2 emissions according to ODIAC)





Conclusions

- CarbonCGI ACI2 scenarios potentially estimate ~20 % of emissions not covered by CO2M with an uncertainty lower than 20 %
- Coupling atmospheric inversions with Compact Gas Imager performance made it possible to optimize the performance of emissions' monitoring versus CarbonCGI technological choices

  → Plan for further analysis accounting for more complex patterns in the surface and atmospheric conditions to refine the assessment of the CarbonCGI ACI2 configurations

  → Further coupling the C-CGI performance simulator with the TRACE atmospheric inversion system

- Results from sensitivity tests (not presented):

→ more systematic analysis of the impact of increasing the spatial resolution vs the precision

→ weak impact of the injection height for point sources

→ moderate impact of the position of the swath with respect to the sources as long as the upwind border of the swath is within 10 km from the center of the source

→ model error, estimated as a bias with inversions with Gaussian model while image generated with LES model: ~20 % to ~10% for point sources and 20-km wide sources respectively