Satellite monitoring of urban CO_2 emissions : an extensive analysis of the OCO-3 SAMs database

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Reporting urban CO2 emissions

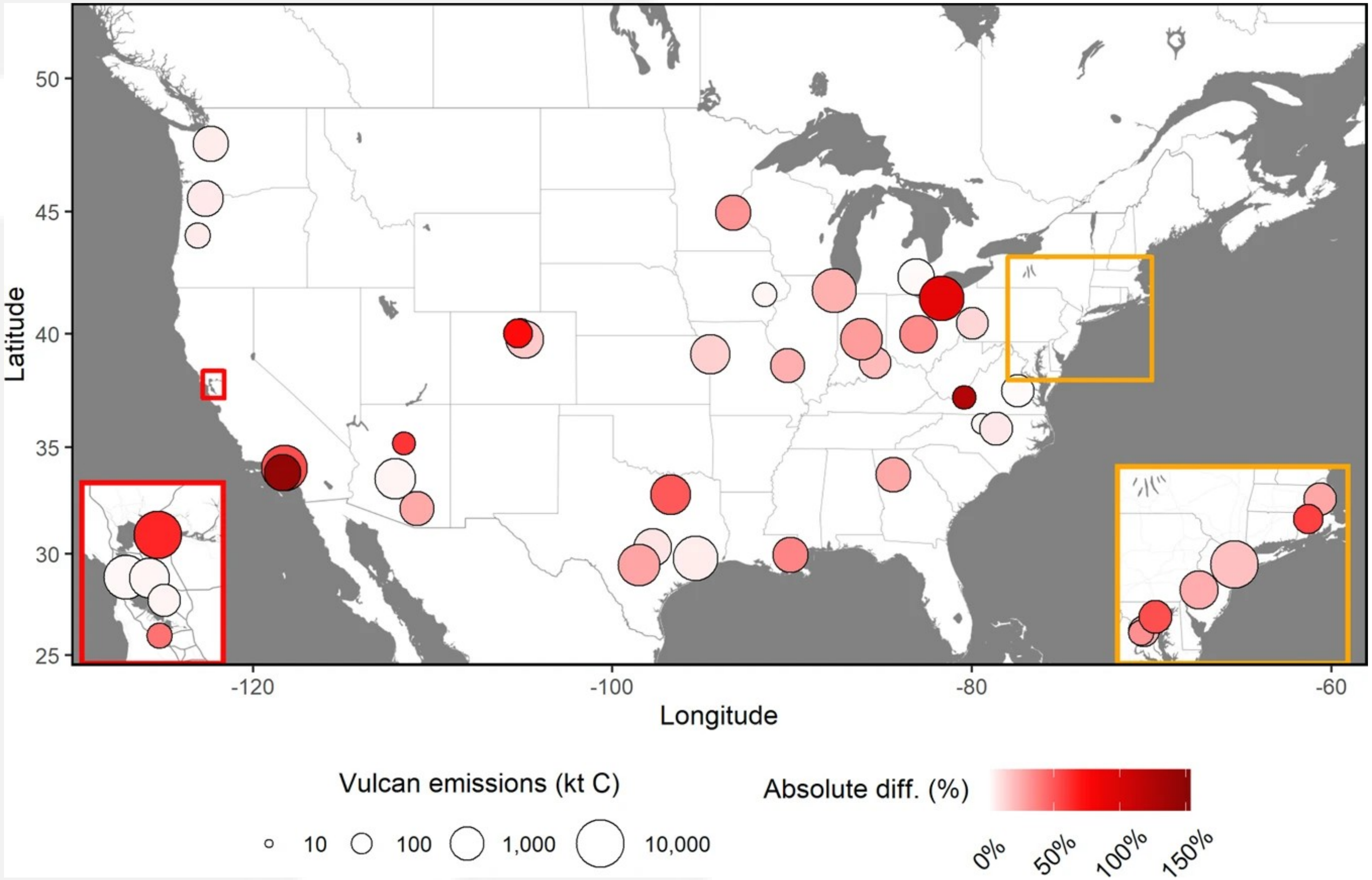


Fig. 1: Total individual city (N = 48) FFCO2 emissions and absolute difference (AD = positive RD) between the Vulcan version 3.0 data product and self-reported inventories (SRIs). (Gurney et al. 2021)

→ **systematic underestimation** of CO2 emissions across US cities in the Self Reported Inventories when compared to Vulcan.

PhD goal

PhD goal : Develop **methods** to estimate **urban CO2 emission** with **satellite** data

→ assess emissions where there is a lack of reporting.

Study of **computationally-light** methods to estimate urban CO2 emissions that can be **applied automatically :**

- **selection of the methods** with synthetic data (test-case over Paris);
- identification of **criteria to select targets** and associate typical error bars (synthetic data with 31 cities simulated);
- application to **OCO-3 data**.

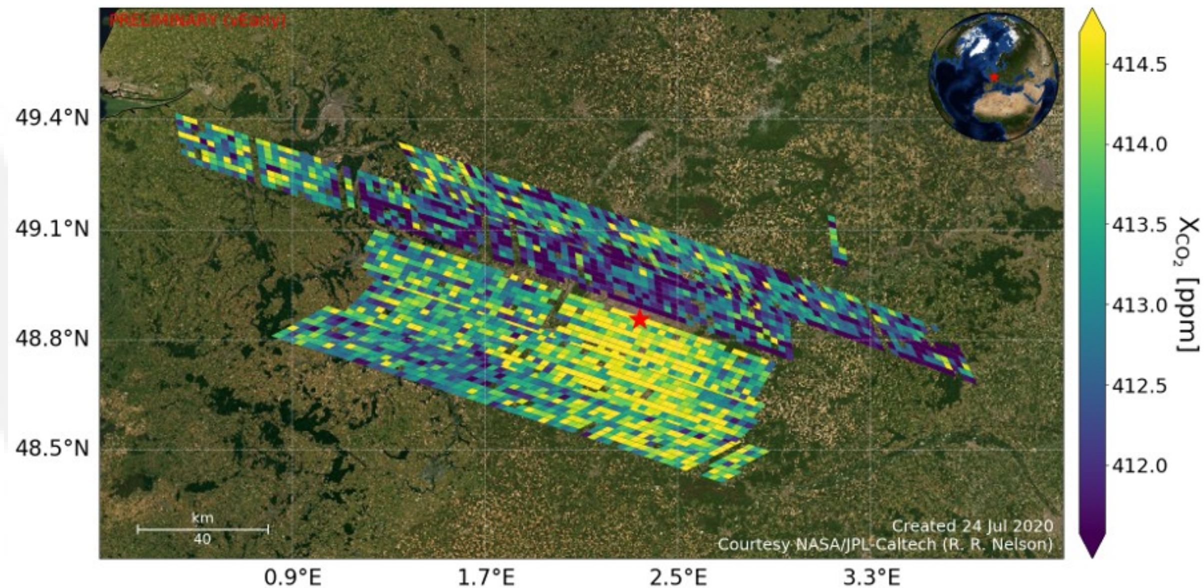
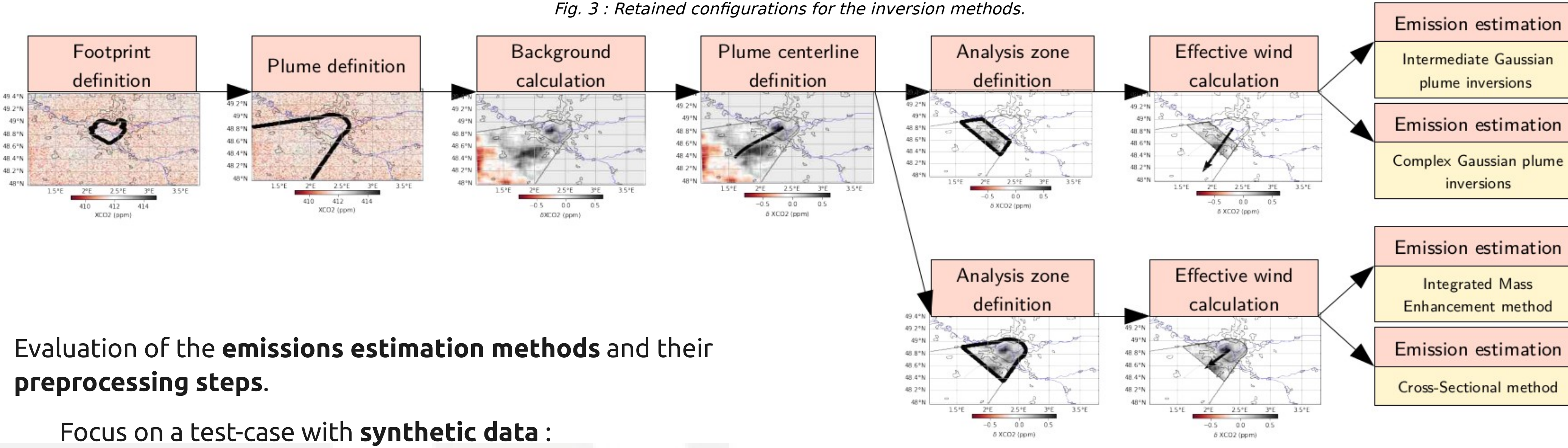


Fig. 2: XCO2 data from OCO-3 SAM over Paris on April 13th 2020.

Fig. 3 : Retained configurations for the inversion methods.



Evaluation of the **emissions estimation methods** and their **preprocessing steps**.

Focus on a test-case with **synthetic data** :

High-resolution simulations of hourly atmospheric CO2 concentrations (WRF-Chem V3.9.1);

Using Origins.Earth inventory.

Aim : (i) **parametrization** of the inversions methods, (ii) **analysis of the sensitivity** of the error.

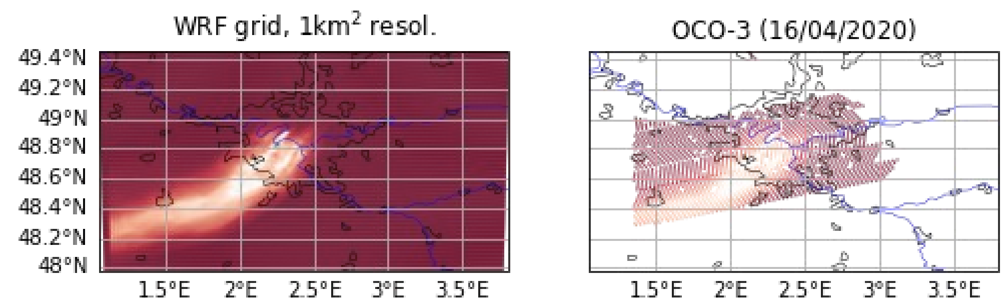
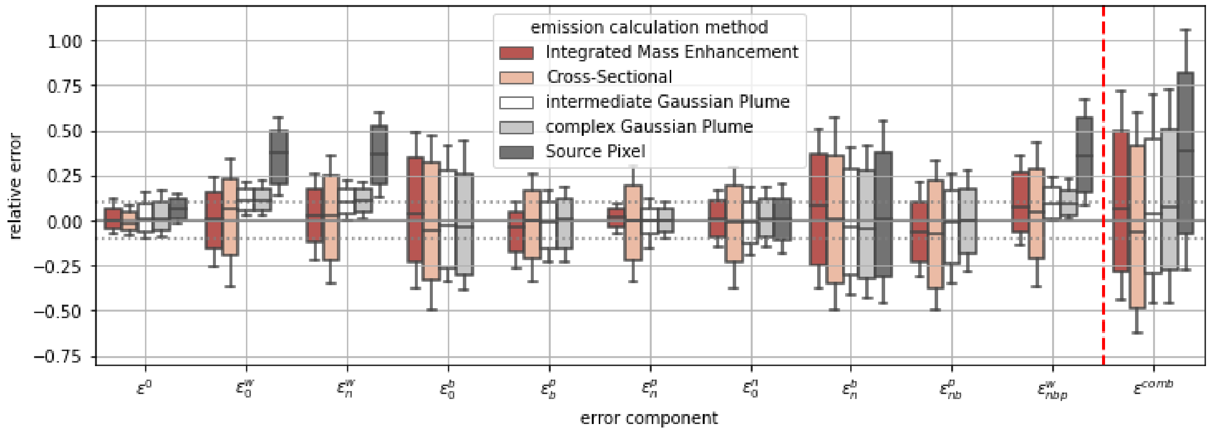


Fig. 4 : Illustration of the samplings used.

1 - Decomposition of the error

Fig. 6: Summary of the different error distribution studied in the retained configurations, after filtering out the simulations with high variability of XCO2 signals (>0.75ppm) and of the wind direction (>8°).



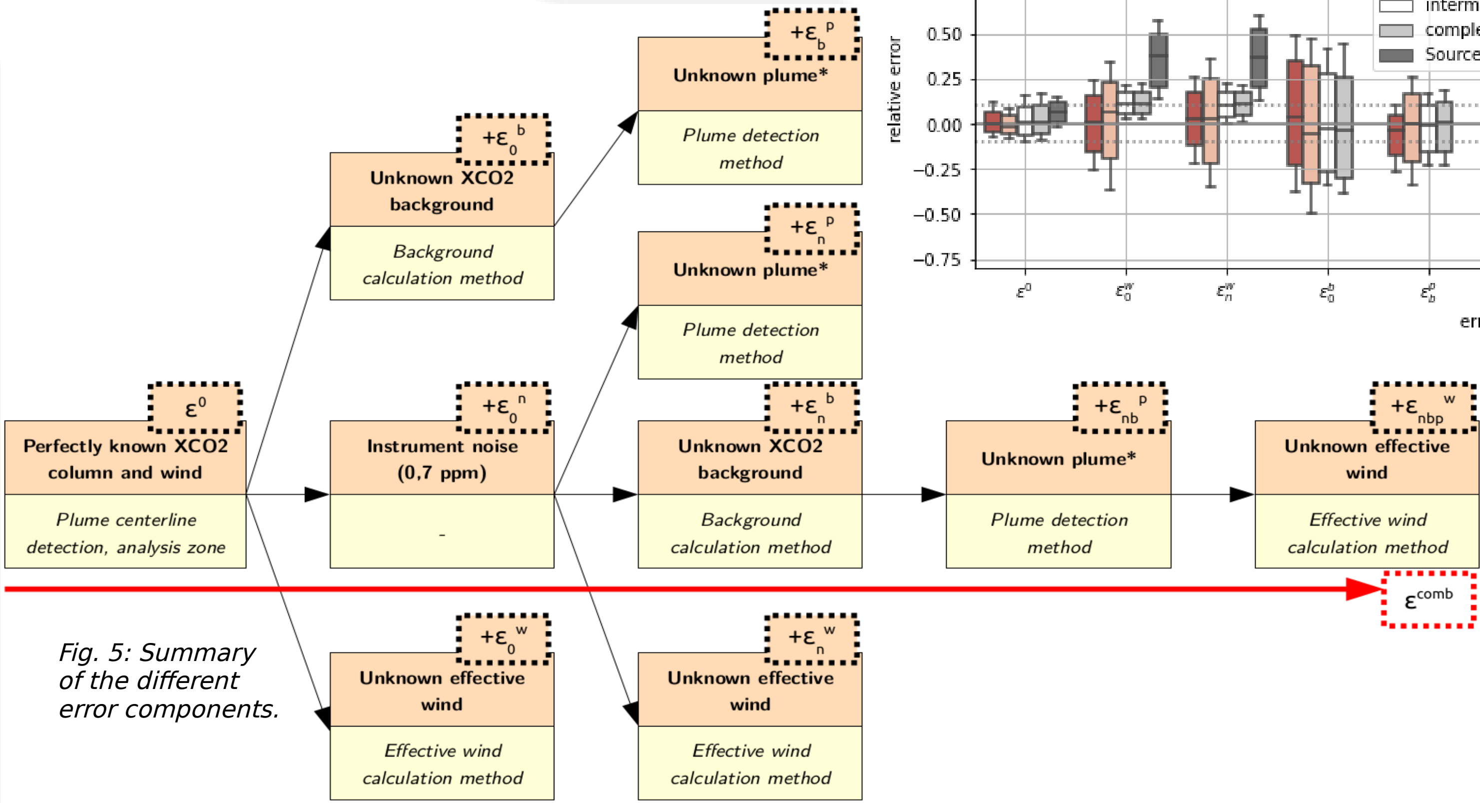


Fig. 5: Summary of the different error components.

1 - Sensitivity of the combined error

Paris test-case	without filtering (100% of data)	with Paris filtering (57% of data)
WRF-grid sampling	6% [-38%,+56%]	4% [-29%,+45%]
OCO-3 like sampling	3% [-43%;+60%]	5% [-37%;+53%]

Table 1 : Total error in percentage of the true emissions.(median [1st quartile, 3rd quartile]). Results are obtained without and with filtering the data, following criteria defined over Paris test-case. Results are shown for the Intermediate Gaussian plume method.

Main conclusions :

- **Small bias** when rightly configured, but **significant spread**;
- Main error sources come from the **background** and **effective wind** estimations.

Two main factors for the precision of the results :

- **spatial variability of the wind direction** in the PBL;
- variability of the XCO2 signal outside of the plume.

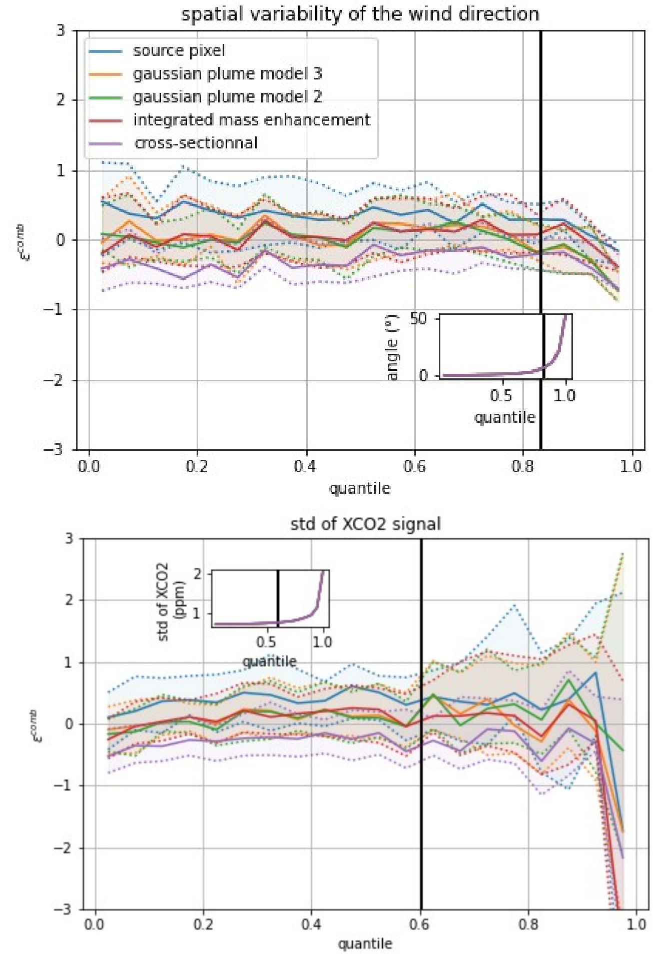


Fig. 7 : Error sensitivity to the spatial variability of the wind in the PBL and to std of the XCO2 signal

2 - Analysis of the sensitivity of the error with synthetic data (31 cities)

Influence of the different **characteristics of a city** (size, compacity,..) and of the **meteorological conditions** on the error on the emission estimation.

- model OLAM ([Schuh et al. 2021]);
- spatial resolution : octahedral variable resolution grid, reprojected on 100x100km^2 images at 3x3km resolution for **31 cities worldwide**;
  - → **optimistic sampling** compared to real satellite data (no clouds)
- temporal coverage : August 2015,
- CO_2 data : ODIAC for anthropogenic emissions, CarbonTracker2017 for biogenic emissions.

→ Analysis of the **sensitivity** of the error distribution to **define objective selection criteria**.

Paris test-case	without filtering (100% of data)	with Paris filtering (57% of data)
WRF-grid sampling *(165x200km, 1x1km)*	6% [-38%,+56%]	4% [-29%,+45%]
OCO-3 like sampling *(~80x80km,~1,7x2km)*	3% [-43%;+60%]	5% [-37%;+53%]

31 cities	without filtering (100% of data)	with Paris filtering (53% of data)
OLAM sampling *(100x100km, 3x3km)*	-16% [-53%,+35%]	-5% [-34%,+30%]

Table 2 : Total error obtained without and with filtering of the data, following criteria defined over Paris test-case. Results are obtained with Intermediate Gaussian plume method.

Criteria found in with Paris test-case **relevant**.

→ can we find **better ones**?

2 - Analysis of the sensitivity of the error with synthetic data (31 cities)

	without filtering (100% of data)	with Paris filtering (53% of data)	with DT filtering (47% of the data)
OLAM sampling	-16% [-53%,+35%]	-5% [-34%,+30%]	-6% [-33%,22%]

Table 3 : Total error obtained with the different filtering strategies.

Application of a **Decision Tree algortihm** to define **criteria of selection** of the pseudo-image :

→ **emission** levels in the city, spatial **variability of the wind** direction.

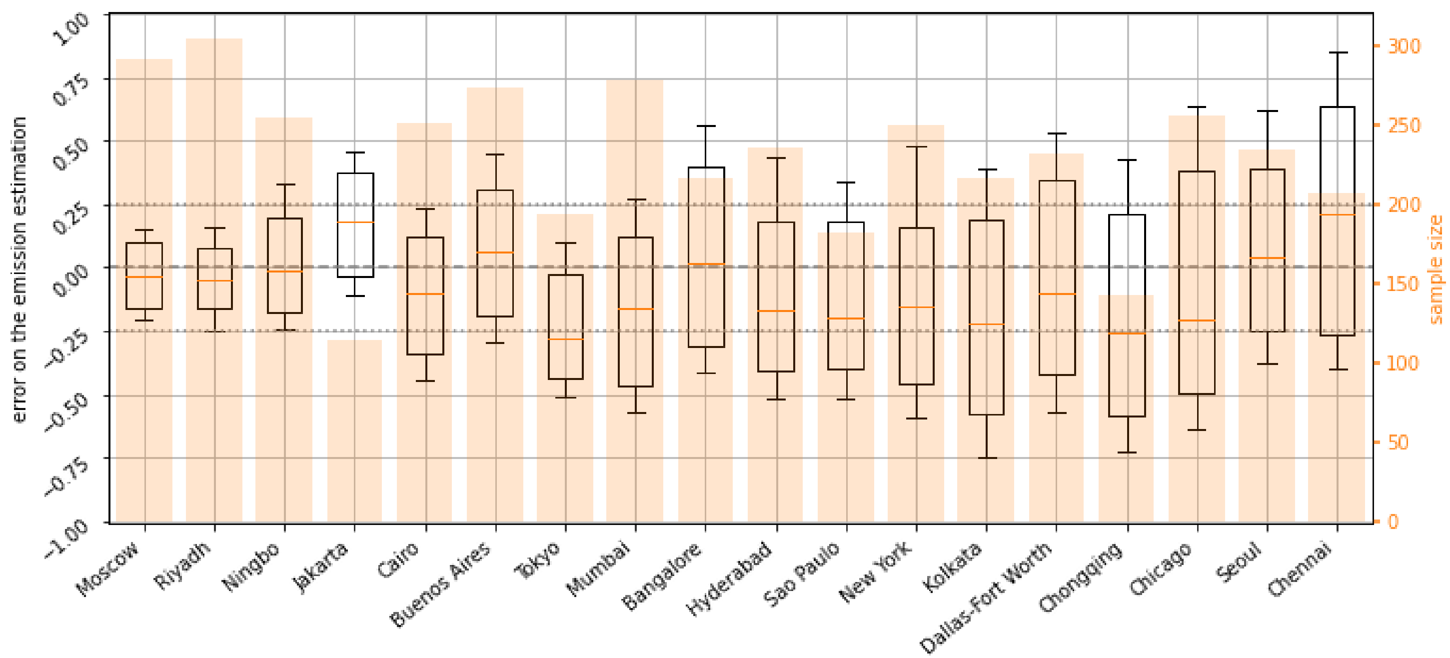


Fig. 8 : Total error distribution obtained for the cities simulated with OLAM using GP2 method.

Only 17 cities left (out of 31) after application of the criteria.

→ **some cities and atmospheric conditions** are **more pertinent** to target than others for satellite inversion with light methods.

3 - Evaluation of urban emissions with OCO-3 SAMs

Application of our methods to SAM database :

- August 2019 to April 2022
- SAMs with more than 1000 points (before L2 quality flag)

→ **2536 images** (SAMs) : 171 cities and 45 powerplants targeted.

Assess the potential of **automatic processing** of the SAMs database with our light methods and **objective filtering criteria**.

- re-assessing the criteria for favorable plume inversion conditions derived from the analysis of pseudo images,
- evaluating emission estimates for sources relatively well known,
- providing insight on emissions for sources for which emissions are more uncertain.

→ ongoing, will only display some examples today.

3 - Performance of our inversion process on the OCO-3 SAMs

	Inversion methods			Commentaires
	GP2	IME	CS	
# success	1551	1977	1632	The calculation performed to the end, we have an emission estimation.
# fail	985	559	904	Not enough pixels, patterns that prevent the method to converge,..

Table 4 : Number of fail and success of the different inversion methods when applied to the OCO-3 SAMs. GP dente the inversion methods based on a gaussian plume model, IME the one using the Integrated Mass Enhancement Method and CS te one using the Cross-Sectional method.

Important proportion of fail, for various reason mainly due to the **SAM configuration** :

→ not enough « good quality » flagged pixels, too few pixels downwind of the plume, spurious patterns that affect the convergence of the optimization, …

Success does not mean a credible estimate..

3 - Examples of inversions : « good » estimation

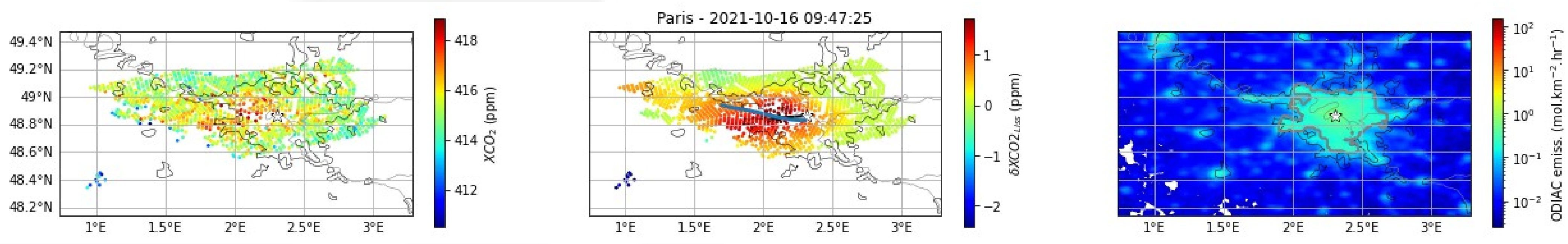


Fig. 8 : SAM taken over Paris on October 16th 2021 with XCO_2 data (right panel), smoothed background removed data (middle panel) and emissions from ODAC (left panel).

	GP2	IME	CS	ODIAC
Emission (ktCO_2/hr)	5,5	5,5	7,7	2,9

Visible plume, coherence between the plume direction and the wind direction.

→ Coherent estimations between the GP2 and IME inversion methods (not CS).

3 - Examples of inversions : «erroneous» estimation

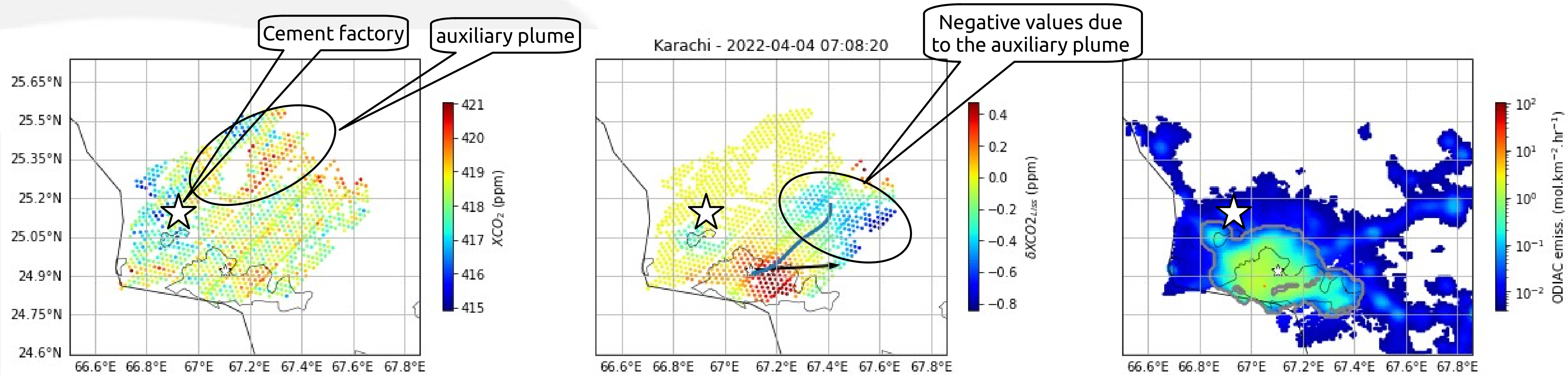


Fig. 9 : SAM taken over Karachi on April 4th 2022 with XCO_2 data (right panel), smoothed background removed data (middle panel) and emissions from ODAC (left panel).

	GP2	IME	CS	ODIAC
Emission (ktCO_2/hr)	-1,4	1,3	1,1	3,5

Cement factory at 25.1°N, 66.9°E.

Overestimated background in the vicinity of the auxiliary plume :

→ negative values in the plume from Karachi.

3 - Examples of inversions : other typical SAMs

	GP2	IME	CS	ODIAC
Emission ($ktCO_2/hr$)	3,3	-0,8	-0,3	1,0

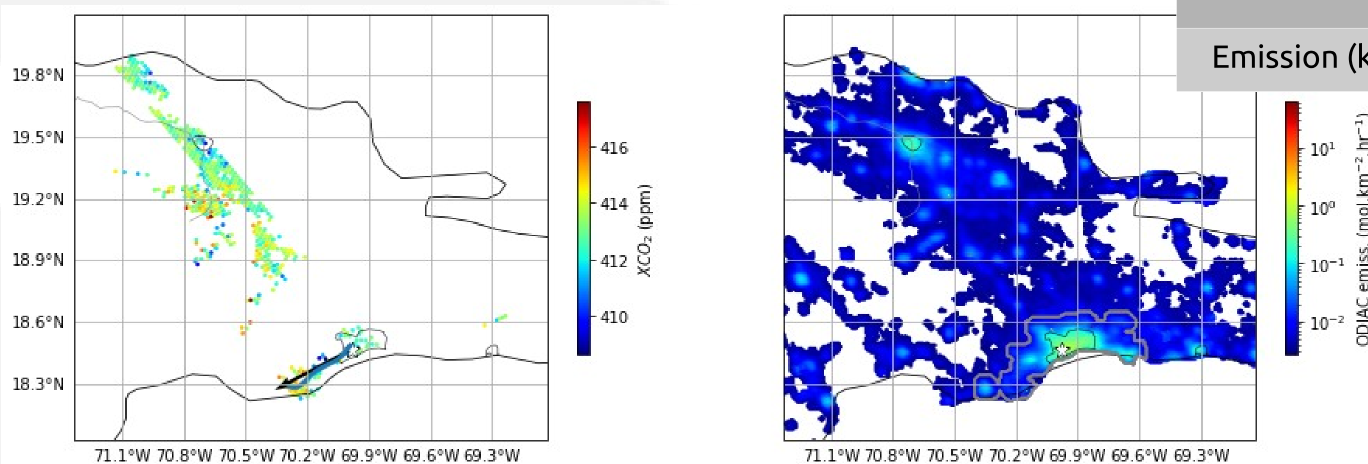


Fig. 10 : SAM taken over San Cristobal on November 2nd 2021 with XCO_2 data (right panel) and emissions from ODAC (left panel).

	GP2	IME	CS	ODIAC
Emission ($ktCO_2/hr$)	1,6	-0,3	-0,2	7,2

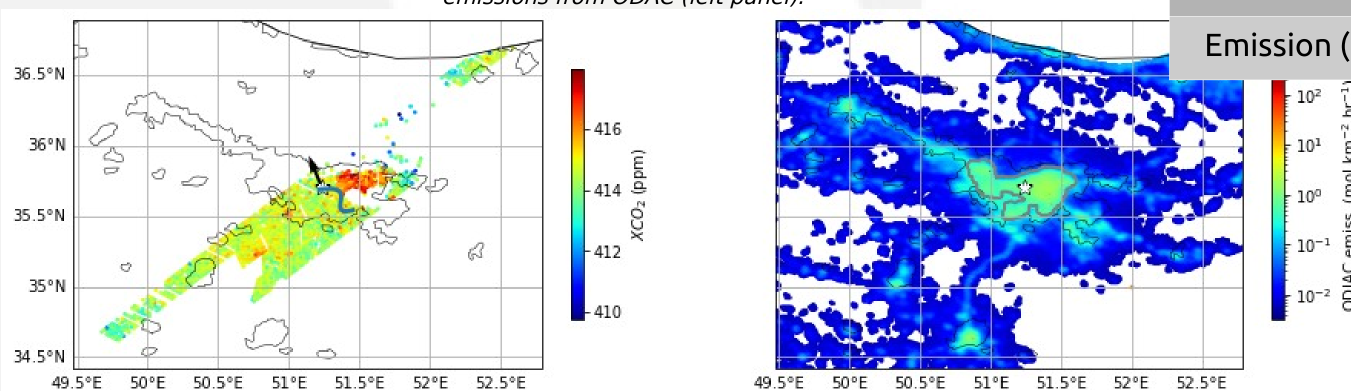


Fig. 11 : SAM taken over Tehran on October 10th 2021 with XCO_2 data (right panel) and emissions from ODAC (left panel).

Conclusions

Studies with **synthetic data** show interesting results for our light methods, but not for every cities.

→ our capacity to provide trustful estimations **depend** mainly on :

- **meteorological conditions** (wind field homogeneity, cloud coverage)
- and the **level of emissions**.

Still work to do to understand the problems we face with real data and define objective selection criteria :

→ we still **need a visual check** to select the SAMs..

Not enough understanding and not enough data yet to provide statistically relevant emission estimation.