Evaluation of light atmospheric plume inversion methods using synthetic XCO2 satellite images to compute Paris CO2 emissions.

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Compare computationnaly light plume inversion methods[a] to estimate city CO2 emissions using synthetic 1km resolution XCO2 images.

Evaluation different configurations and pre-processing options[b].

Experiments based on synthetic XCO2 images over Paris with WRF-Chem[c].

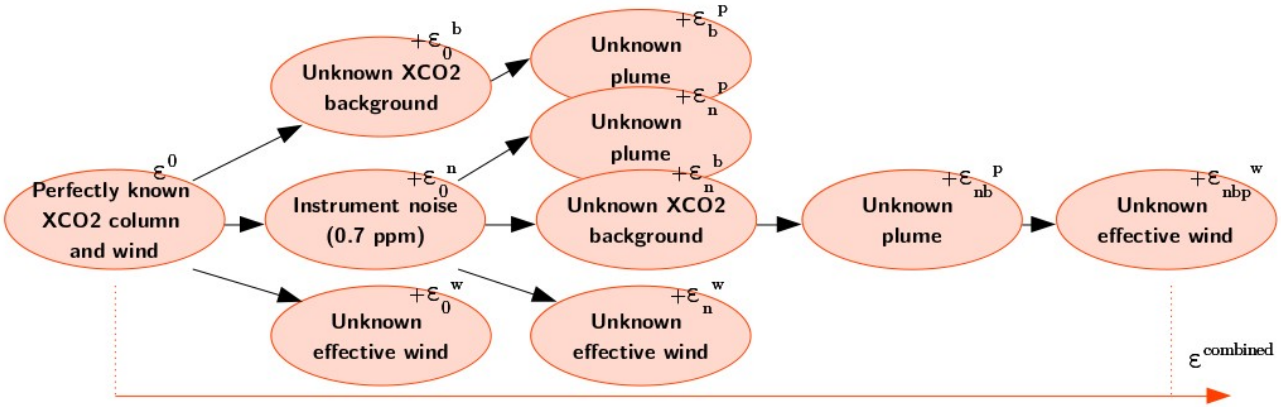
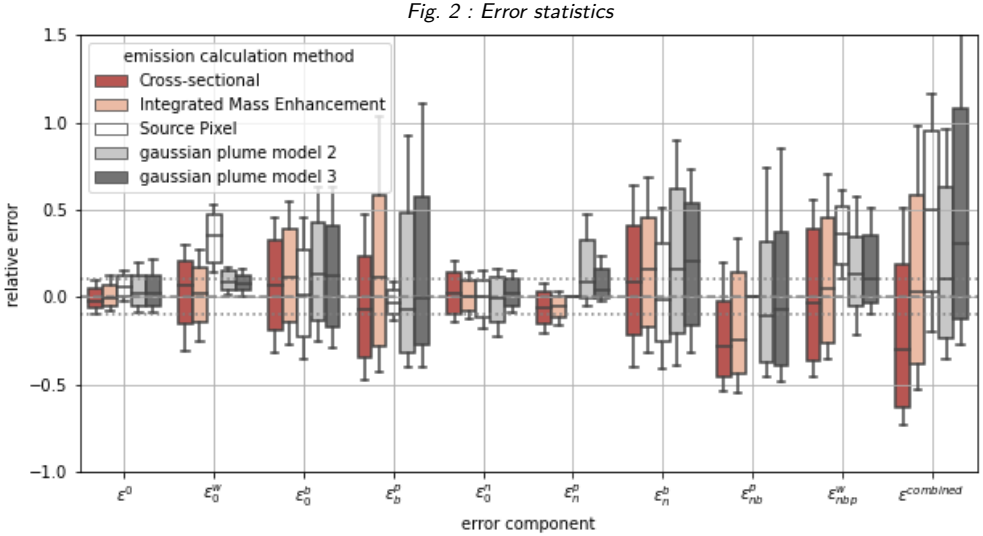


Fig. 1 : Summary of the different error component.

Fig. 2 : Error statistics



Preliminary results

- Main error due to uncertainties in the plume detection and background computation.

- All the methods rely on assumption of stationarity : low precision when high temporal/spatial variations in the wind.

- Seasonal dependency → seasonal variation of SNR and of the wind variability.

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a. Varon et al. 2018, Quantifying methane point sources from fine-scale satellite observations of atmospheric methane plumes. *Atmos. Meas. Tech. 11*
b. Kuhlmann et al. 2019, Detectability of CO2 emission plumes of cities and power plants with the Copernicus Anthropogenic CO2 Monitoring (CO2M) mission . *Atmos. Meas. Tech., 12.*
c. Lian et al. 2020, Quantitative evaluation of the uncertainty sources for the modeling of atmospheric CO2 concentration within and in the vicinity of Paris city, *Atmos. Chem. Phys. Discuss*

Generation of the pseudo-images and inversion techniques

Configuration for the WRF-Chem simulations for the XCO2 images

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

- one-way nesting of three modeling domains (D01, D02, and D03 in Figure 1a) at 25, 5 and 1 km horizontal resolution respectively;
- simulations from December 1rst 2019 to April 30th 2020;
- 165kmx200km coverage for domain D03.

High resolution anthropogenic emission inventory : combination of Origins (Suez) and ODIAC.

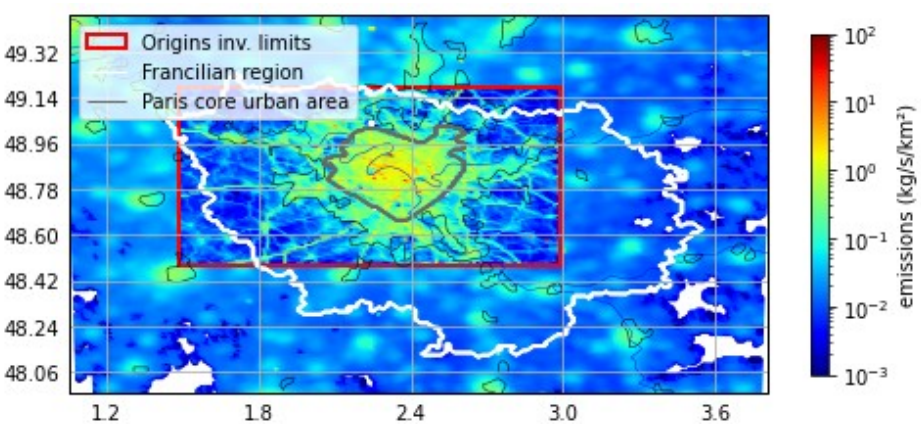

Fig. 3 : Map of the anthropoganic emissions used. Red line indicates the limits of Origins product. Gray line indicates the limits of the targeted zone for the emission calculation.

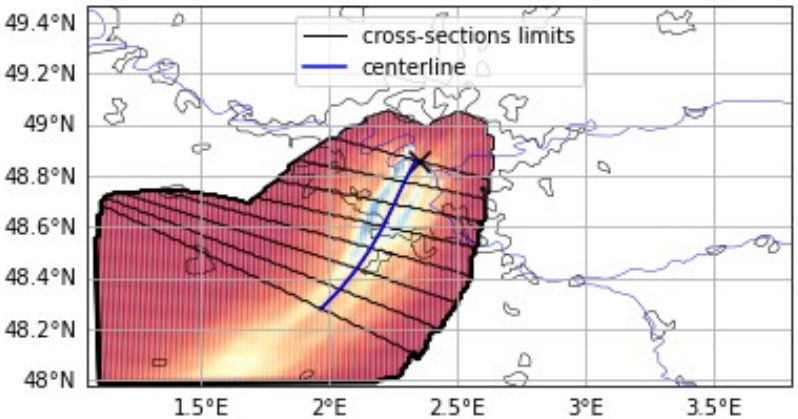

Fig. 4 : Illustration of the cross-section used for the cross-sectionnal method and gaussian plume based model adapted to turning plume.

Inversion methods

Computationnaly light methods of emissions estimation for urban CO_2 :

- Direct flux integration methods (Integrated Mass Enhancement, Cross-sectional and Source Pixel methods);
- Gaussian plume based models.

→ Adaptation to turning plumes.

Evaluation of different pre-processing methods :

- estimation of the effective wind, calculation of the background emissions, detection of the plume limits.

→ In the inversion methods, the plume is restricted to a plume sampling zone by rejecting the plume cross-sections at less than 0 or 20km of the city center and the ones at more than 40 or 60 km.

Experimental framework : ensemble of test to stimate the different components of the error

Starting from an ideal case (with perfectly known background, effective wind and plume limits and without measurement noise), we introduce the sources of errors step by step.

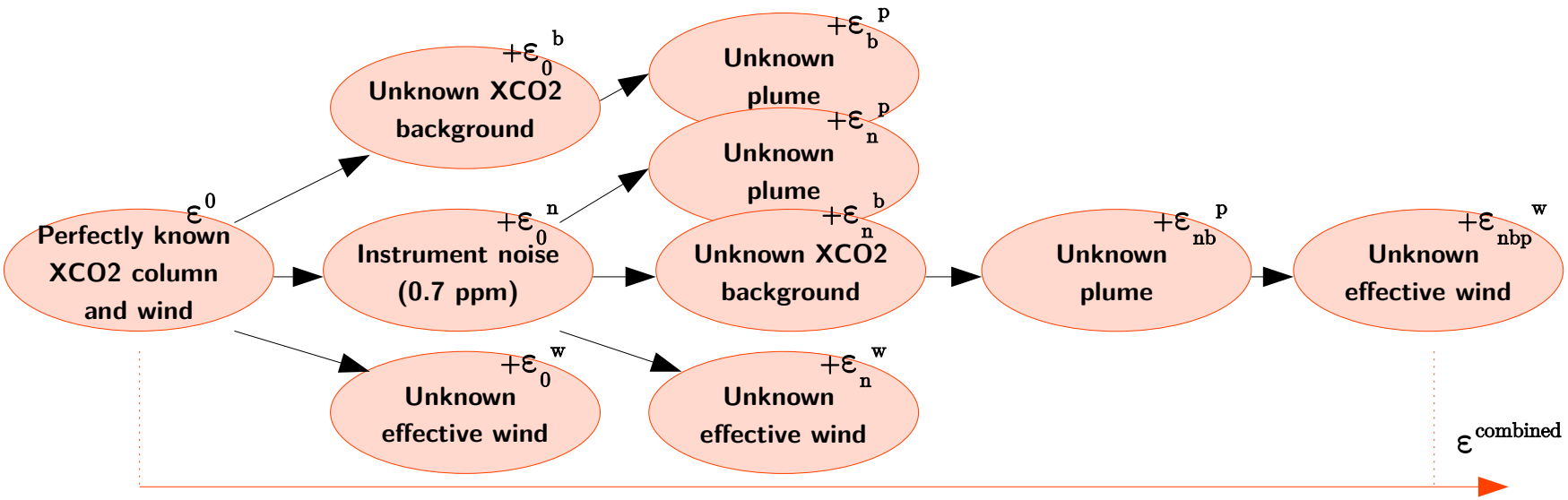

Fig. 5 : Summary of the evaluated errors

Result when having a perfect knowledge of the XCO2 column and wind field (ε^0)

Results of the cross-section method when applied to indidual cross-section

Cross-section method : result average all cross-section of the plume. Here we analyze the result per cross-section.

- Precision decreases with the distance to the city.
- Precision decreases with the wind 3D variability in the PBL.
- Complex sensitivity to the definition of the centerline.

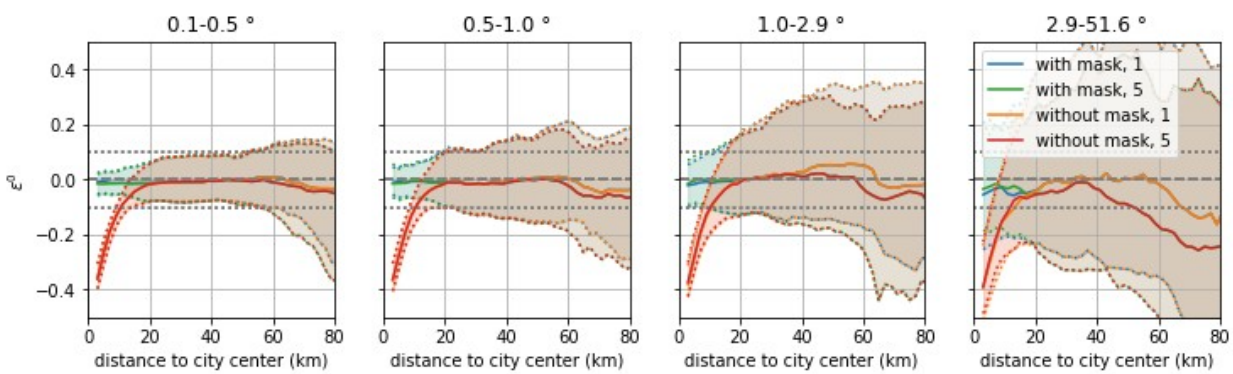

Fig. 6 : Evolution of the error in function of the cross-section using the cross-sectionnal method. Results are separated for the different quartiles of variability of the wind direction in the PBL. Blue and orange lines show result obtained using a linear centerline, green and red with a centerline fitted by a 5th order polynom. Blue and green lines show result when only the emission upwind of the cross-sectio are used as reference to calculate the error, orange and red when all the emission from the core urban area are used as reference.

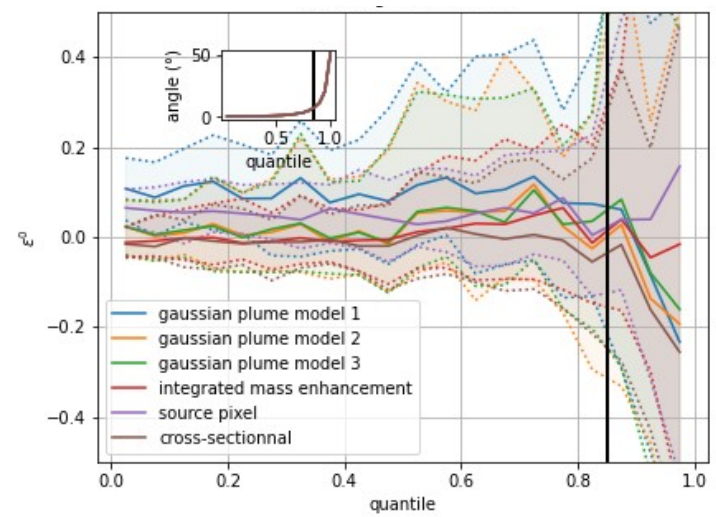

Fig. 7 : Evolution of the error in the ideal case in function of the variability of the wind direction in the PBL. Results are separated per emission calculation methods.

Error dependency to meteorological conditions

The precision of the emission calculation methods decreases when high variability of the wind direction in the PBL:

$\rightarrow$ removing the 15% of the data with the highest variability of the wind direction increase the precision of the results.

Adding other sources of uncertainties.

Error (ε^w) due to the effective wind estimation

3 different winds tested to estimate the effective wind :

- 10-m surface wind : need correction with a multiplivative coefficient (1.8 on figure 8); give small spread and bias dependent of the plume sampling zone.

- mean wind in the PBL : small spread but important bias when the plume sampling zone is close to the source.

- tangent wind to the plume centerline : small bias but important spread.

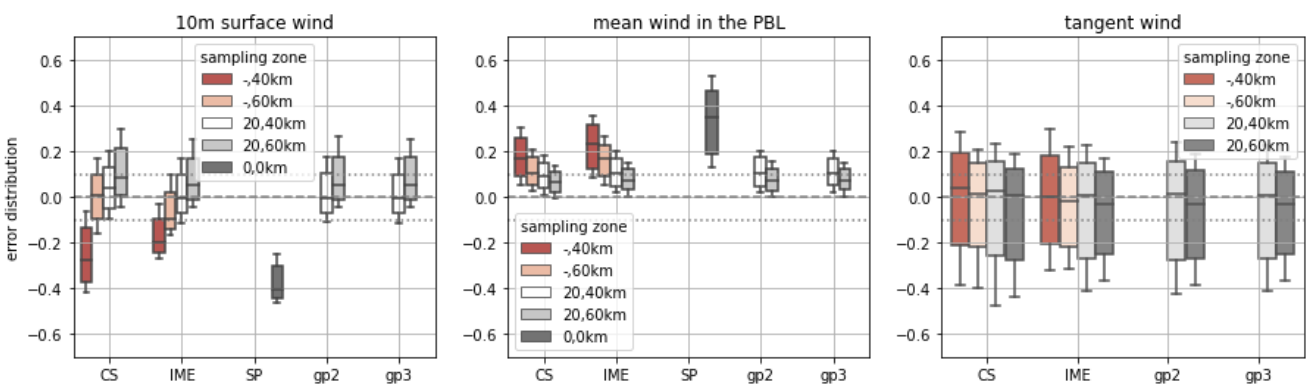

Fig. 8 : Evolution of the error due to effective wind estimation step. Results are shown for the different emission calculation methods and the different plume sampling zone for each tested effective wind estimation method.

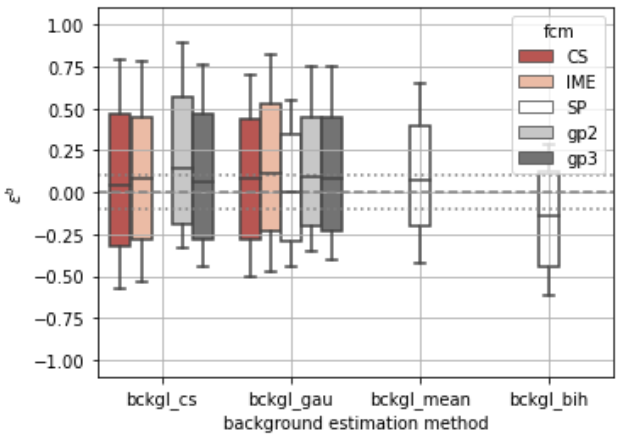

Fig. 9 : Evolution of the error due to background estimation step. Results are shown for the different emission calculation methods for the 20,60km plume sampling zone.

Error due to the background calculation (ε^b)

- Nearly unbiased results when the plume limits are known.

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Synthesis of the uncertainties

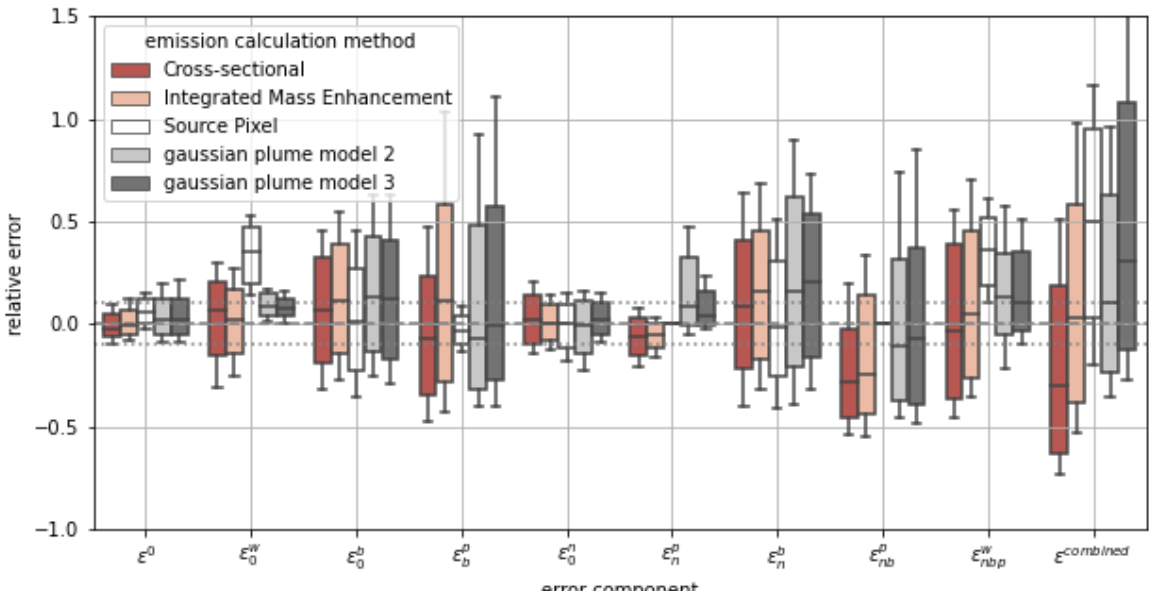

Fig. 10 : Error statistics (wok in progress). Results are filtered based on their wind varaibility (removing 15% of the data) and portion of the image occupied by the plume (keeping plume occupying more than 5% of the image but less than 40%).

Preliminary results

- Main error due to uncertainties in the plume detection and background computation.

- All the methods rely on assumption of stationarity : low precision when high temporal/spatial variations in the wind.

- Seasonal dependency → seasonal variation of SNR and of the wind variability.

Out of the scope : Uncertainty in the wind 4D field, loss of data due to cloud cover, systematic errors on XCO2 images.