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Evaluation of light atmospheric plume inversion methods using synthetic XCO2 satellite images to compute Paris CO_2 emissions.

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An increasingly-large number of cities have designed ambitious climate mitigation plans to contribute to national GHG emission reduction objectives, typically starting with city-scale accountability of their direct and indirect fossil fuel emissions (Self Reported Inventories). Several concepts of spaceborne instruments providing high resolution 2D view of CO_2 total column concentrations (XCO2) have been developed to monitor the CO_2 anthropogenic emissions. Those images target mainly the CO_2 atmospheric plumes from cities and large power plants, expecting that their study may quantify the emissions of those sources. However, there is still a need to develop and asses estimation methods which could process a large number of images in a robust way for such quantifications.

In this study, we evaluate the ability to quantify CO_2 urban emissions from XCO2 2D images by conducting sensitivity experiments with synthetic images over the Paris area during the winter 2019/2020. Synthetic data were simulated using state-of-the-art mesoscale model simulations at 1km resolution coupled to a high-resolution inventory, all validated against in situ CO_2 tower measurements. We compared multiple direct flux calculation methods as described in various studies including Source Pixel, Integrated Mass Enhancement and Cross-sectional methods [Varon et al.,2018], further examined with various configurations, in addition to several formulations of Gaussian plume inversion techniques. These methods are computationally affordable compared to mesoscale inversions based on Eulerian or Lagrangian models, hence able to process rapidly a large amount of data over various cities in the future.

We quantified the uncertainties and accuracy for these methods using different combinations of assumptions to i) identify the plume from the city, ii) to determine the corresponding background concentrations from natural and anthropogenic sources outside the city, and iii) to estimate the effective wind speed and direction of the plume. From this large ensemble of approaches and configurations, we identified the most robust methods and parametrizations with their corresponding precisions under various meteorological conditions and specifications of the XCO2 images (esp. spatial resolution and measurement errors).

Starting with ideal cases without measurement noise and with perfectly known transport, we further increase the complexity of the experiments towards more realistic conditions in order to quantify the impact of the various sources of uncertainties (i.e. measurement errors, uncertainties in background conditions, uncertain plume detection, transport uncertainties). We show that most methods have to be adapted to handle the spatial extent of the targeted sources and that their performance are good in near steady state conditions. The source pixel method seems to be the less suited for extended source estimation. However, the final uncertainty is mainly driven by the pre-processing steps (background, plume limits and effective wind estimations).