Deriving CO_2 emissions of localized sources from OCO-3 XCO_2 and TROPOMI NO_2 data

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Introduction

Carbon dioxide (CO_2) is the most important anthropogenic greenhouse gas leading to climate change and is mostly emitted by localized sources in the combustion of fossil fuels.

Emissions need to be monitored to track reduction efforts to comply with the objectives of the Paris Agreement. Top-down emission estimates can complement and verify bottom-up estimates [1].

The detection of CO_2 emission plumes and quantification of anthropogenic fluxes is challenging due to the small column-average concentrations resulting from anthropogenic emissions from individual point sources, compared to the background concentration and the satellite's instrument noise.

NO_2 is co-emitted with CO_2 in the combustion of fossil fuels and its vertical column densities can exceed background values and sensor noise by orders of magnitude in emission plumes. Therefore, it is a suitable tracer for recently emitted CO_2 [2].

Datasets

XCO_2 NASA's v10 level 2 Snapshot Area Maps (SAMs) retrieved by the Orbiting Carbon Observatory 3 (OCO-3) onboard the International Space Station.

NO_2 slant column densities (SCD) from the IUP Bremen retrieved by TROPOMI, onboard the Sentinel 5 Precursor (S5P), using DOAS (Differential Optical Absorption Spectroscopy).

Meteorological data from ECMWF's ERA5.

Generated power per unit from the European Network of Transmission System Operators for Electricity (ENTSO-E).

Method

We estimated the CO_2 emissions using a cross-sectional flux method: by mass balance, the source rate is given by the flux through all cross sections downwind of the source.

1. Plume detection using NO_2 SCD

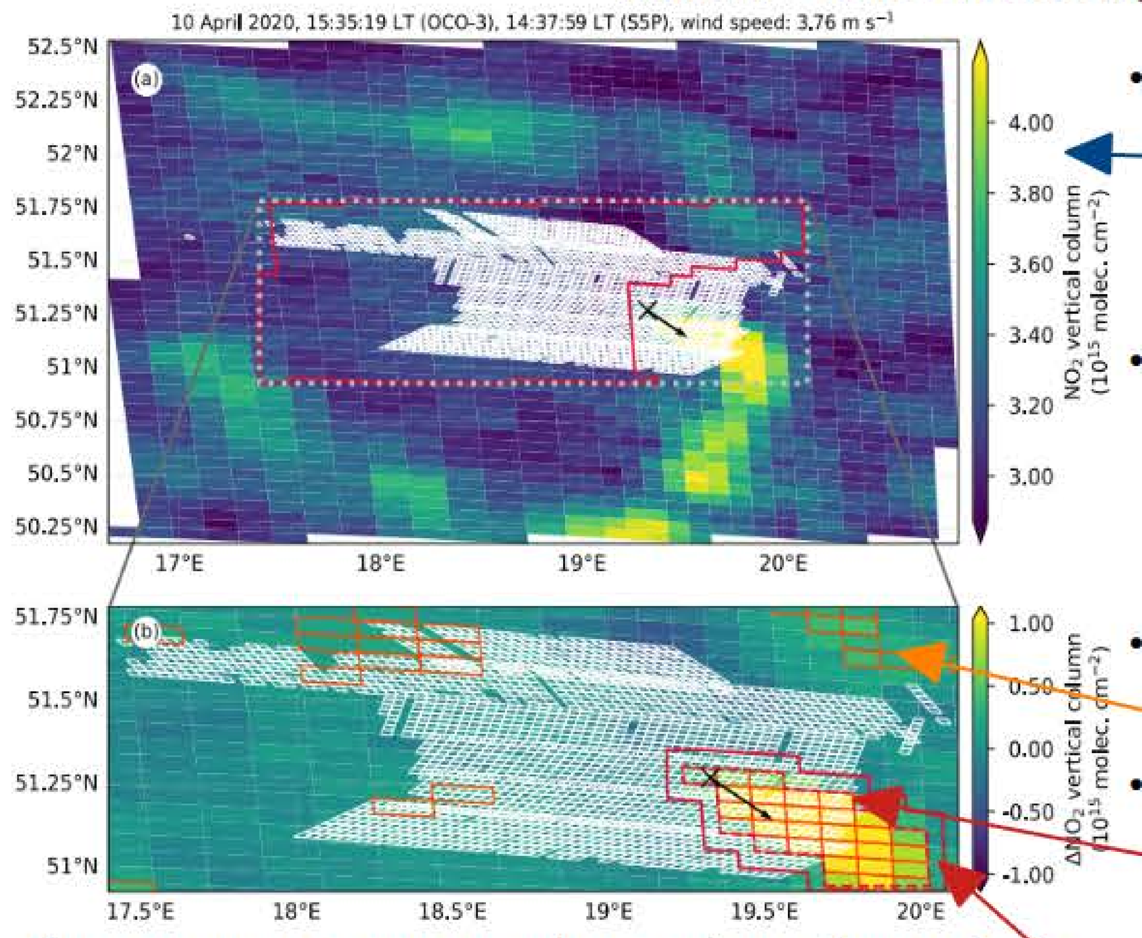

Figure 1. S5P NO_2 VCD **(a)** and NO_2 enhanced VCD (after background subtraction) **(b)** over the Bełchatów Power Station, whose location is marked as a black cross. The borders of the SAM pixels are marked as white polygons.

- Geometrical approximation of **vertical column densities (VCD)** and spacial averaging to reduce random noise.
- Background subtraction to remove stratospheric and large-scale tropospheric components.
- T-test to select **observations with enhanced VCD**.
- Clustering, selection of the **cluster closest to the source** (Fig. 1) and extension parallel to its borders to obtain the **potential plume**.

2. Flux estimation from XCO_2 data

- Background modelling (linear function of longitude and latitude), and subtraction from XCO_2 values to obtain the enhancements, ΔXCO_2 (Fig. 2).
- Average horizontal wind within the boundary layer weighted by the number of dry air particles (n_e), at the centre of each OCO-3 pixel.
- Filling in missing XCO_2 values by Inverse Distance Weighting (IDW) interpolation.
- Flux for each cross section (CS), k, perpendicular to plume track (Fig. 2), as:

$$\Phi_k = \frac{M_{CO_2}}{N_A} \sum_i v_{\perp,i} n_{e,i} \Delta l_i (\Delta XCO_2)_i ,$$

i: each pixel along k-th CS
$v_\perp$: horizontal wind speed perpendicular to CS
Δl_i: length of pixel i

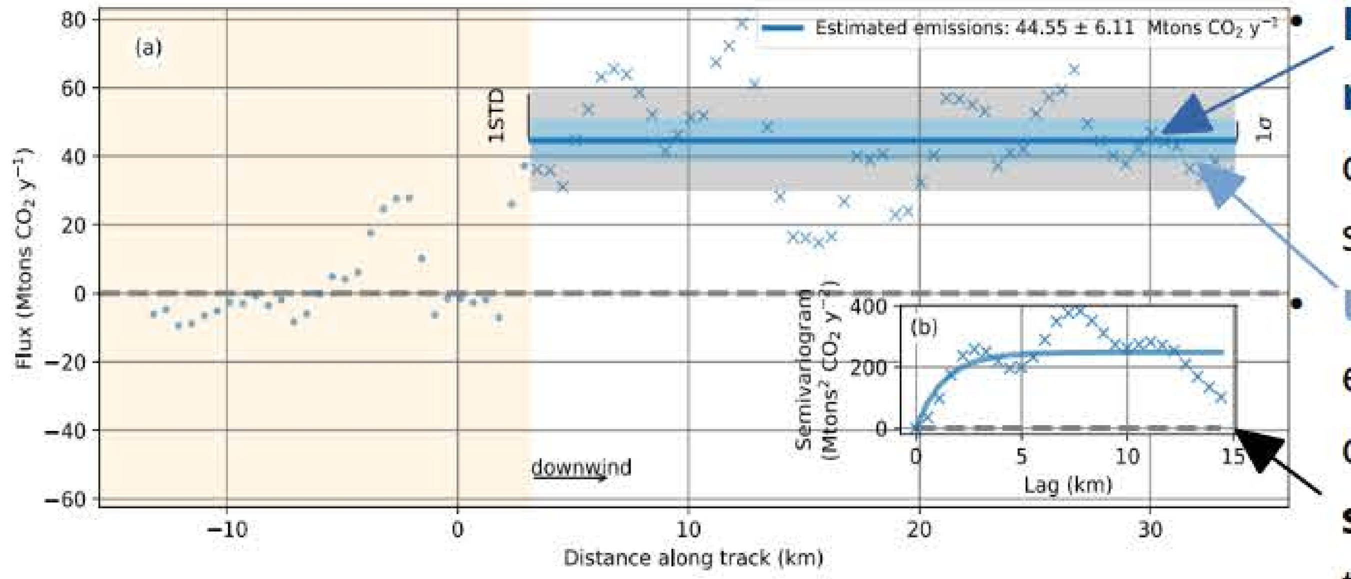

Figure 3. **(a)** Computed cross-sectional fluxes down-wind (upwind) of the source, represented as crosses (dots). **(b)** Semivariogram.

- **Estimated emission rate**: mean of the computed cross-sectional fluxes.
- **Uncertainty**: standard error of the mean computed from a **semivariogram** to take auto-correlation into account.

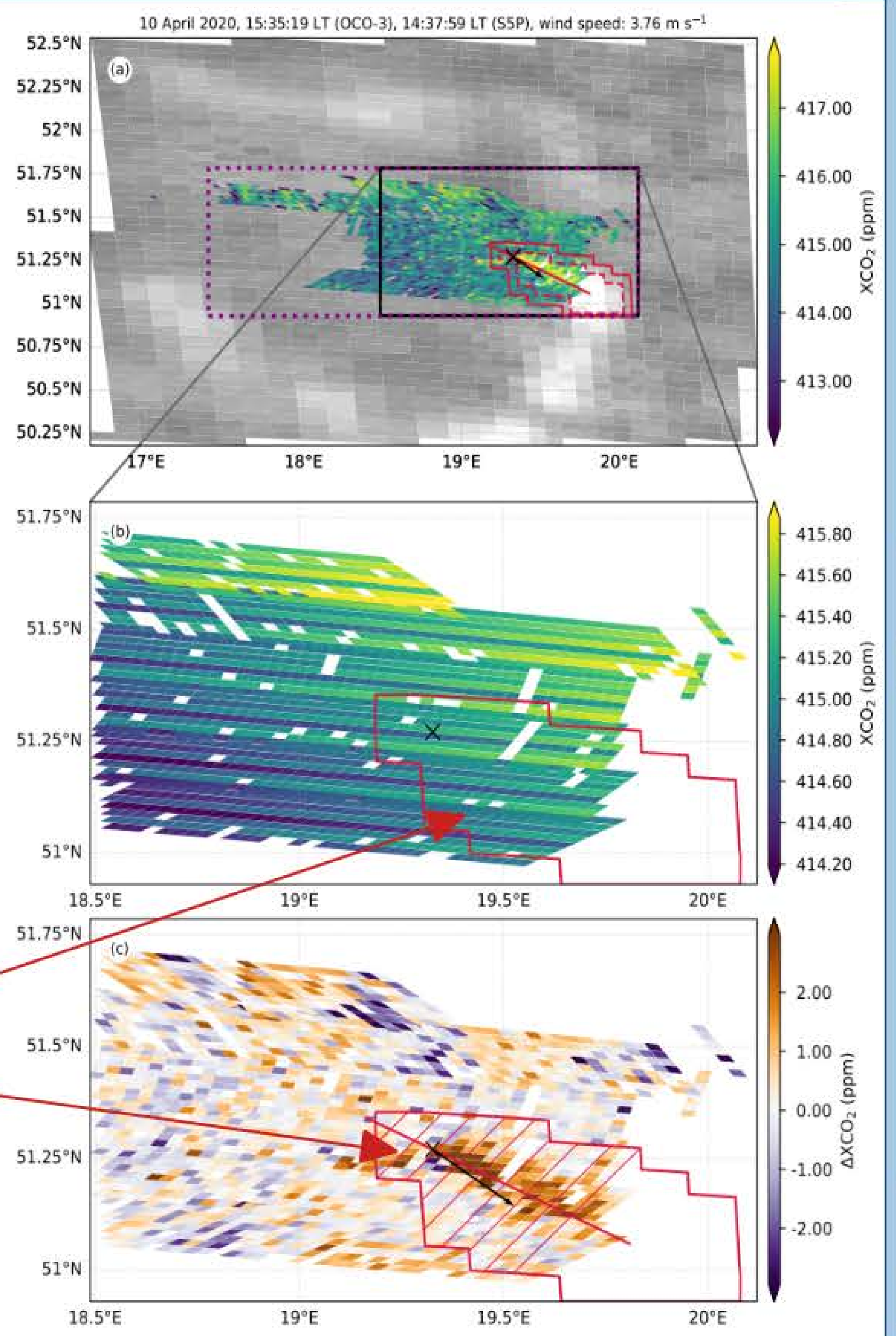

Figure 2. **(a)** OCO-3 XCO_2 SAM over the Bełchatów Power Station. **(b)** Background model. **(c)** XCO_2 enhancements. The average horizontal wind within the potential plume is depicted as a black arrow at the source location. A subset of CS are shown as red solid lines perpendicular to the plume track.

3. Bottom-up emissions

Estimation of emitted emissions from the hourly generated power times an emission factor depending on the type of coal used. We compute a higher (lower) limit assuming the use of only lignite (bituminous coal), and a most likely estimate assuming the average lignite-bituminous coal ratio used by the power plant. We average the hourly emissions within the estimated time interval that the CO_2 spends in the scene.

Results

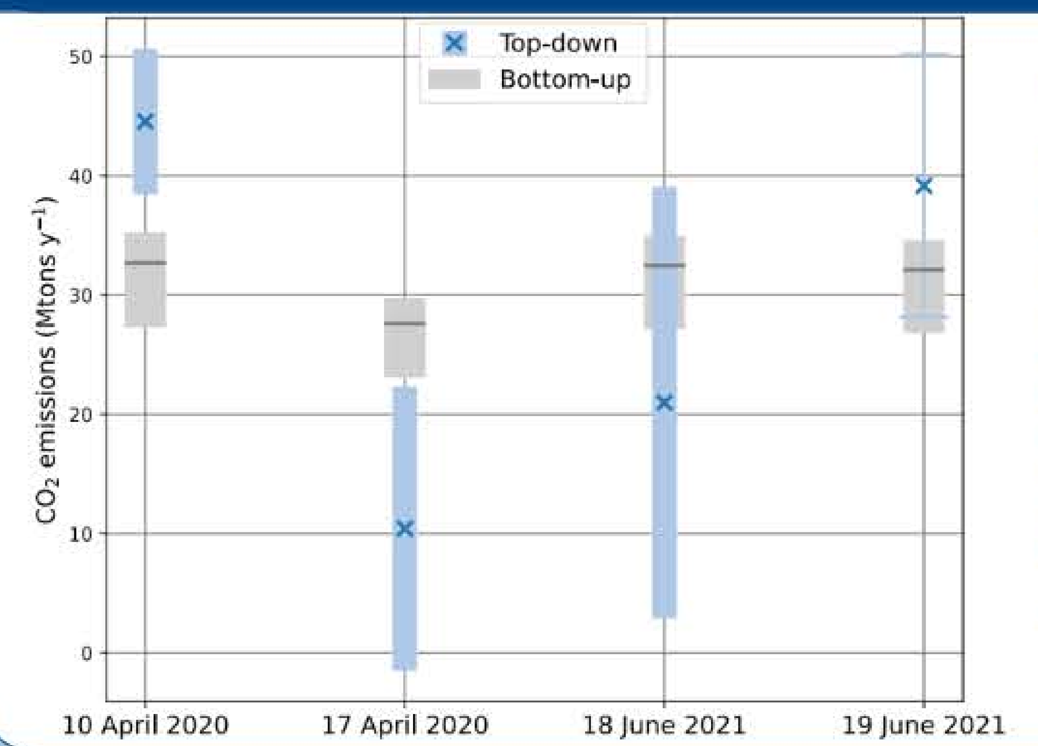

Figure 4. Top-down estimated emission rate (blue crosses) of the Bełchatów Power Station for four different overpasses, together with its uncertainty (blue bars). The bottom-up calculated emissions for three different assumptions on the lignite-coal consumption ratio are shown along as gray bars, where the most likely value is shown as a dark gray mark.

Conclusions and discussion

- Co-located observations of NO_2 and CO_2 help us detect the emission plume and characterize its shape.
- We are able to repeatedly monitor power plant CO_2 emissions. Our top-down estimates agree in 2 of 4 cases, within their uncertainty range, with the bottom-up calculated emissions.
- We estimated the emission uncertainty from the variability of the computed cross-sectional fluxes. However, this estimate is still incomplete, as, e.g., wind speed uncertainty is not yet considered. This may explain the differences between our top-down and bottom-up estimates shown in Fig. 4.

Acknowledgments

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References

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