Deriving CO_2 emissions of localized sources from OCO-3 XCO_2 and S5P NO_2 data

B. Fuentes Andrade, M. Buchwitz, M. Reuter, H. Bovensmann, J.P. Burrows

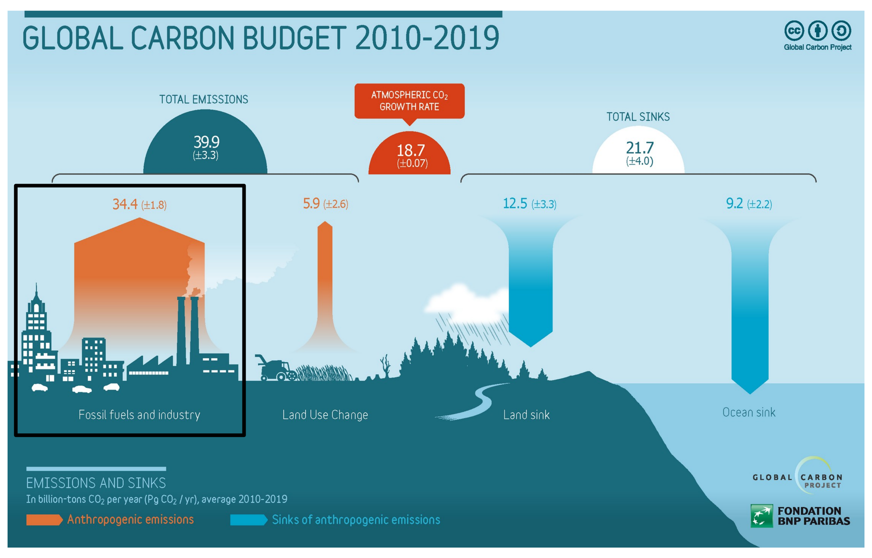
Institute of Environmental Physics, University of Bremen

Introduction

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

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

The Orbiting Carbon Observatory 3 (OCO-3), onboard the International Space Station since 2019, with its high spatial resolution and its Snapshot Area Map (SAM) observing mode, is optimized to study anthropogenic CO_2 fluxes.



Friedlingstein et al. 2020. Earth System Science Data.

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 a suitable tracer for recently emitted CO_2, since it 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, co-located observations of CO_2 and NO_2 allow us to detect the emission plume and its shape [2,3].

Datasets

XCO_2

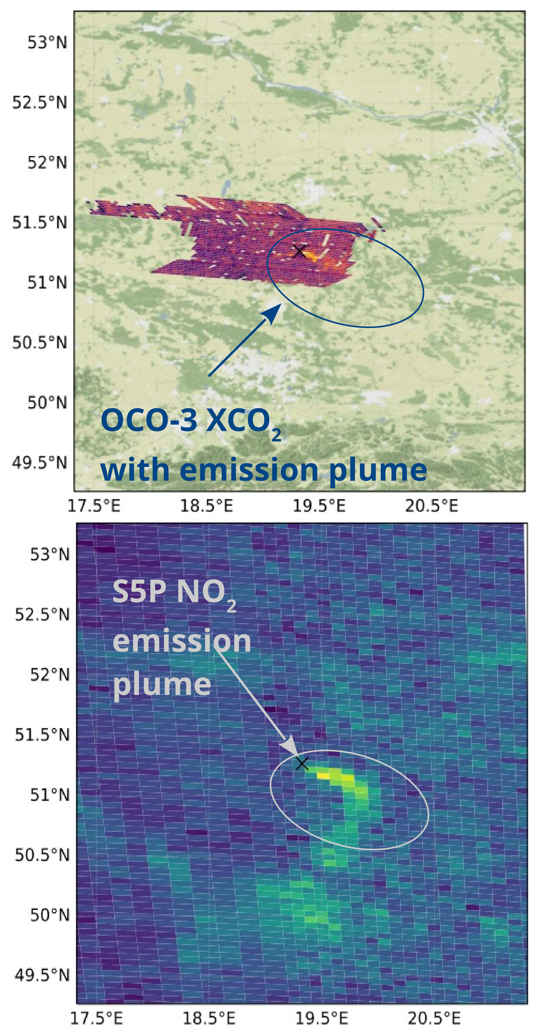
We use OCO-3 level 2 XCO_2 SAMs from NASA, with spatial resolution of about 1.6 x 2.2 km², in its vEarly version.

NO_2

TROPOMI slant columns, retrieved using DOAS (Differential Optical Absorption Spectroscopy), from the IUP Bremen are used along. TROPOMI is onboard the Sentinel 5 Precursor (S5P) and its spatial resolution is about 3.5 x 7 km² at nadir.

Meteorological data

ERA5 Reanalysis from ECMWF, with hourly temporal resolution and 0.1° x 0.1° spatial resolution.



Example of OCO-3 XCO_2 SAM (top) and TROPOMI NO_2 (bottom) scene.

Method to estimate CO_2 emissions

A cross-sectional flux method is used to estimate the CO_2 emissions, so that, by mass balance, the source rate is given by the flux through any cross section downwind of the source. Our procedure consists of the following steps:

1. Plume detection and characterization using NO_2 slant column densities

From the NO_2 slant column densities (SCD), shown in fig. a, an estimation of the vertical column densities (VCD) is approximated using geometrical considerations, followed by a spacial averaging to reduce random noise (fig. b) [2]. Under the assumption of a Gaussian background, a representative mean of the background is computed and used to detect the observations with enhanced VCD performing a statistical t-test (fig. c). The detected enhancements are clustered and the cluster closest to the source is selected and extended parallel to its borders (fig d) to account for different overpassing times of OCO-3 and S5P.

2. Background subtraction

Using XCO_2 data (fig f., left), the background is fitted to a linear function of the longitude and the latitude, allowing for possible footprint and swath biases. The fitted background function is then subtracted from the XCO_2 values to obtain the enhancements, ΔXCO_2 (fig. f, right).

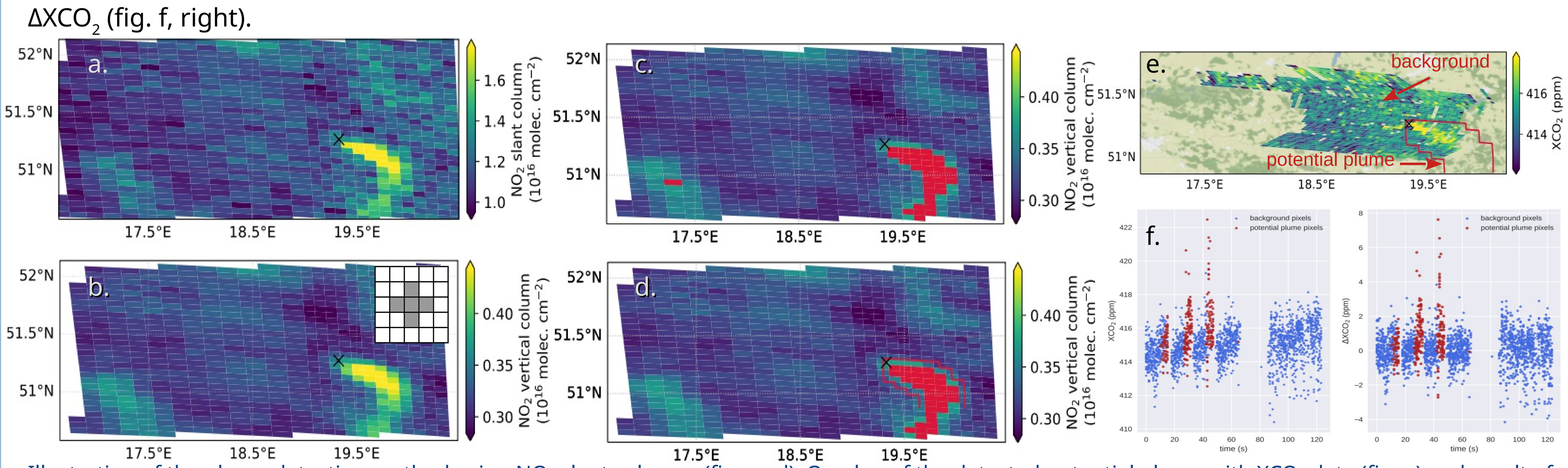


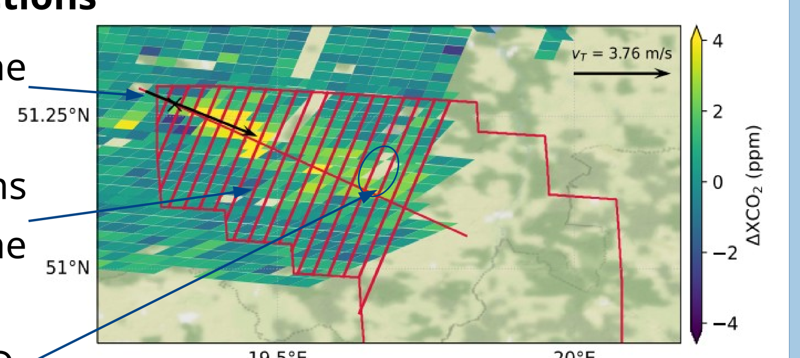
Illustration of the plume detection method using NO_2 slant columns (figs. a-d). Overlap of the detected potential plume with XCO_2 data (fig. e) and result of background subtraction to the XCO_2 data (fig. f).

3. Definition of cross sections

First, we need to find the track of the plume.

We define cross sections (CS) perpendicular to the plume track.

And we fill in missing XCO_2 values using an Inverse Distance Weighting (IDW) interpolation.



Zoomed-in potential plume overlapping with the XCO_2 enhancements, together with the plume track and a number of cross sections. The horizontal wind (as described in step 4) is shown as a black arrow.

4. Getting meteorological information

We get the horizontal wind components and number of dry air particles (n_e) from ERA5 at the centre of each CS at different vertical layers and compute the average of each wind component within the boundary layer weighted by n_e.

5. Computation of the flux across each CS

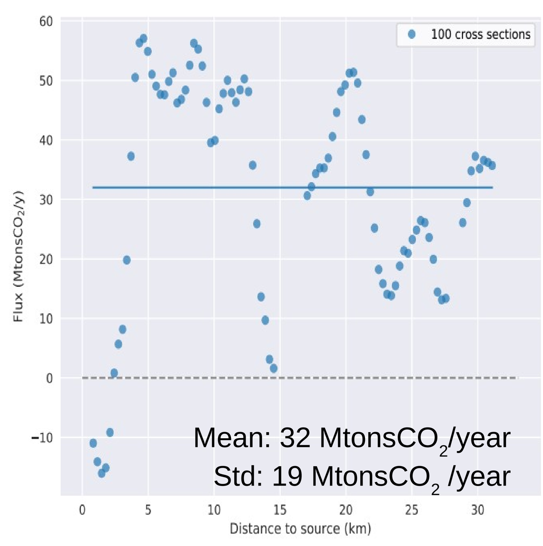
The cross-sectional flux for each CS, k, is computed as

$$\Phi_k = \frac{v_\perp n_e M_{CO_2}}{N_A} \sum \Delta l_i (\Delta XCO_2)_i ,$$

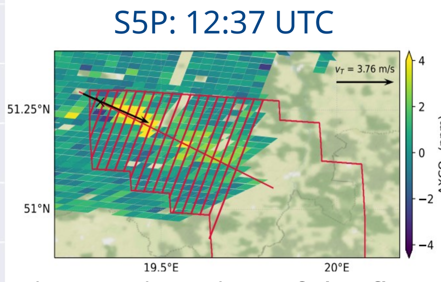
where $v_\perp$ is the wind speed perpendicular to the CS, N_A the Avogadro number, M_{CO2} the molar mass of CO_2, Δl_i the length of each pixel i along the CS and $\Delta XCO_{2,i}$ is the XCO_2 enhancement in that pixel.

Results

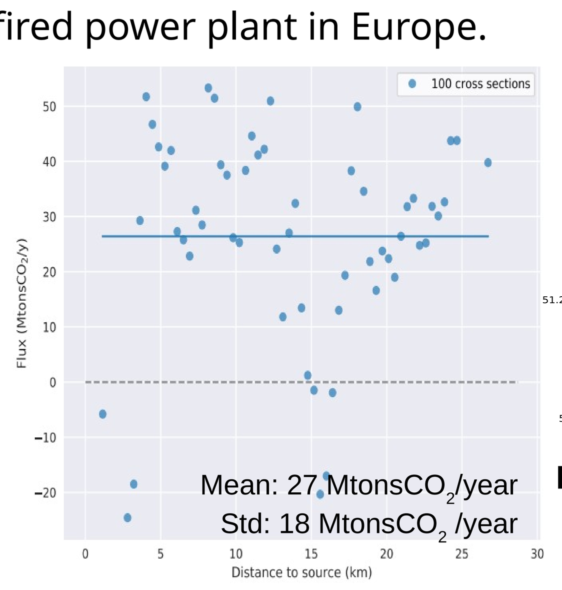
Initial focus: Bełchatów Power Station, in Poland, the largest lignite-fired power plant in Europe.



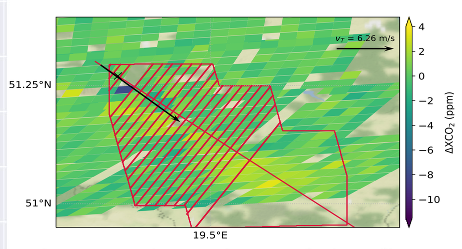
10/04/2020
OCO-3: 13:35 UTC
S5P: 12:37 UTC



First estimation of the flux:
32 $MtonsCO_2$/year



17/04/2020
OCO-3: 09:42 UTC
S5P: 12:06 UTC



First estimation of the flux:
27 $MtonsCO_2$/year

First estimations of the CO_2 emissions of the Bełchatów Power Station. The scatter plots show the cross-sectional fluxes (dots) and its mean (solid line); the maps show the XCO_2 enhancements and the shape of the potential plume together with its track and some of the CSs.

Conclusions and discussion

We developed a method to estimate the CO_2 emissions from localized sources. Our first estimations are in the same order of magnitude as the annual emissions: 37.6 $MtonsCO_2$ in 2017, as reported by the E-PRTR (European Pollutant Release and Transfer Register). However, they are approximately at overpass time and not an annual average, and therefore need to be compared to databases with higher temporal resolution for verification. The uncertainty also needs to be estimated; here we show only the standard deviation.

Other targets need to be analysed, for which we are developing an automatic procedure to select promising scenes.

References

[1] Janssens-Maenhout, G., B. Pinty, M. Dowell, H. Zunker, E. Andersson, G. Balsamo, J.-L. Bézy, et al. *Toward an Operational Anthropogenic CO2 Emissions Monitoring and Verification Support Capacity*. Bulletin of the American Meteorological Society 101, no. 8 (1 August 2020): E1439–51. https://doi.org/10.1175/BAMS-D-19-0017.1.

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Acknowledgements

Financial support was provided by the German Meteorological Service, DWD, grant number 4819EMF06A. The OCO-3 XCO_2 data were produced by the OCO-3 project at the Jet Propulsion Laboratory, California Institute of Technology, and obtained from the OCO-2 data archive maintained at the NASA Goddard Earth Science Data and Information Services Center. The TROPOMI NO_2 data were produced by the Institute of Environmental Physics, University of Bremen. ERA5 meteorological information was obtained from the Copernicus Climate Change Service (C3S) (2017), operated by the ECMWF.

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