Quantifying Greenhouse Gas Emissions from Point Sources

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Large industrial facilities are responsible for over half of global anthropogenic CO_2 emissions, making their independent monitoring vital for climate mitigation efforts. Satellite observations provide valuable insights but often lack the spatial resolution needed at the facility scale. In this study, we combine ground-based remote sensing measurements with atmospheric modelling to track and quantify greenhouse gas emissions from the Bremen steelworks. This approach highlights both the potential and current challenges of integrating measurements and models for accurate facility-level emission estimates.

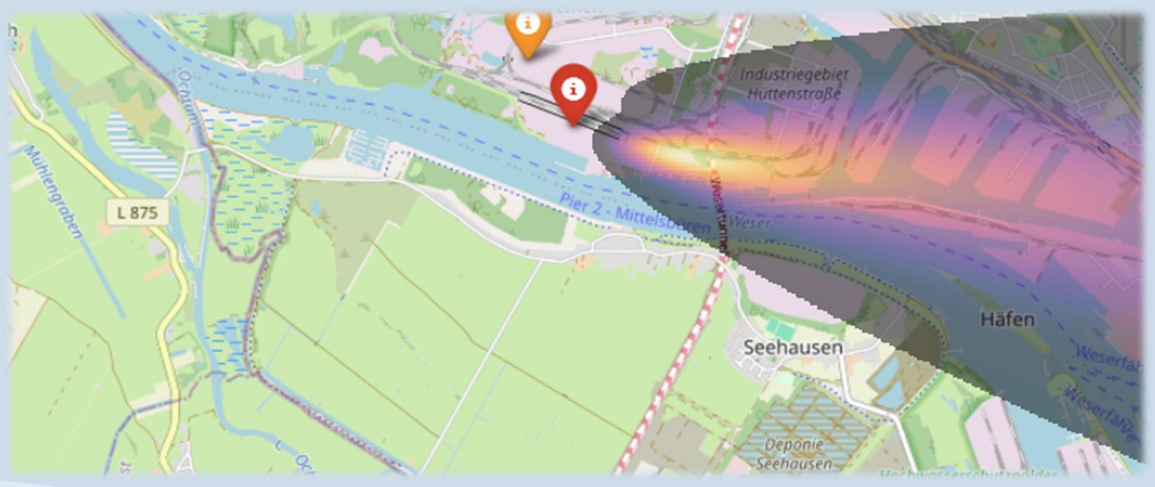
Ground-based Remote Sensing of the Emission Plume

Two stationary **EM27/SUN** FTIR solar absorption spectrometers provide precise and accurate measurements of column-averaged abundances of CO_2, CH_4, and CO downwind of the emission stacks with a spectral resolution of 0.5 cm^{-1}.

Mobile zenith-sky **DOAS** measurements taken from a car monitor the behaviour of the plume in the changing wind field. These measurements are used to determine the vertical column density of co-emitted NO_2 as a tracer for the emission plume. The rapid retrieval enables real-time plume tracking and helps determine its behaviour.

The wind field up to 300 m is observed with a **Wind-LIDAR** ZX300. It records 15 sec mean values of wind direction and wind speed with a precision of 0.1 m/s for speed and 0.5° for direction.

Atmospheric Dispersion Modelling



Emission dispersion is simulated with the **Gaussian dispersion model**

$$C(x,y,z) = \frac{Q}{2\pi u \sigma_y \sigma_z} * \exp\left(-\frac{y^2}{2\sigma_y^2}\right) * \left[\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right)\right]$$

Calculations of the effective stack height and usage of the dispersion coefficients according to the atmospheric stability determined by wind speed and solar insolation (Hanna et al. 1982) are included. The horizontal dispersion resulting from this modelling approach was compared to the actual measured plume width from the DOAS measurements. For intervals with DOAS data, measured plume locations were used to constrain the Gaussian model for preliminary emission estimates.

Emission Characterisation and Estimates

Measurements from both the DOAS and the EM27/SUN instruments clearly show the emission plume. The EM27/SUN records increases in column-averaged abundances of up to 5 ppm in XCO_2 and up to 200 ppb in XCO at a distance of 2 km from the source. The DOAS measurements reveal plume cross sections of Gaussian shape in the vertical column values of NO_2.

Changes in wind conditions shift the plume in and out of the observed atmospheric column. From simultaneous changes in XCO and XCO_2 an emission ratio $\Delta XCO/\Delta XCO_2$ was derived. The **CO/CO_2 emission ratio** obtained gives a mean value of 3.46 ± 0.85 %. Satellite-based studies (Schneising et al. 2024) report a ratio of 6.28 ± 4.09 %, while inventory records indicate a value of 3.33 % (Umweltbundesamt 2022).

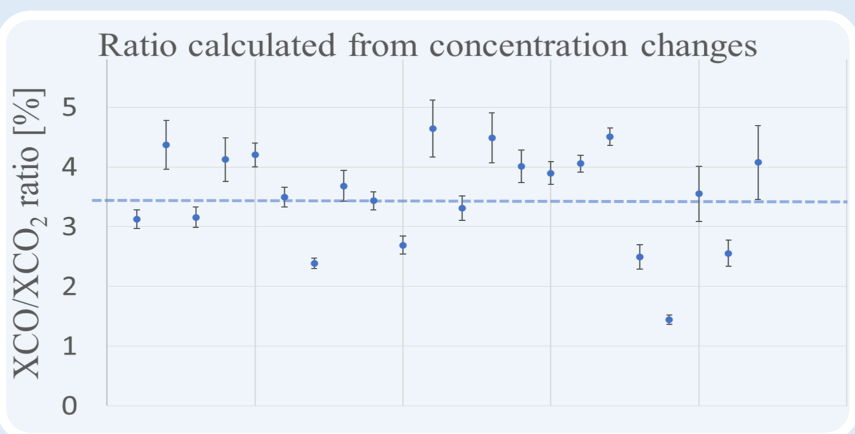


Fig. 1: Calculated CO/CO2 emission ratios.

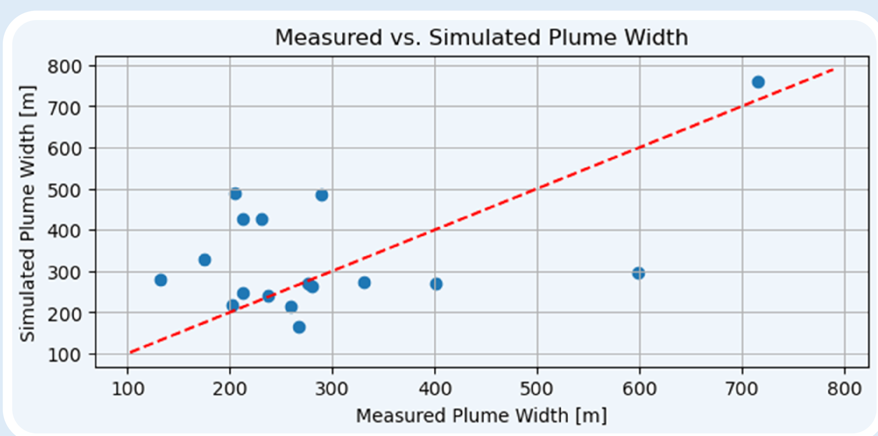
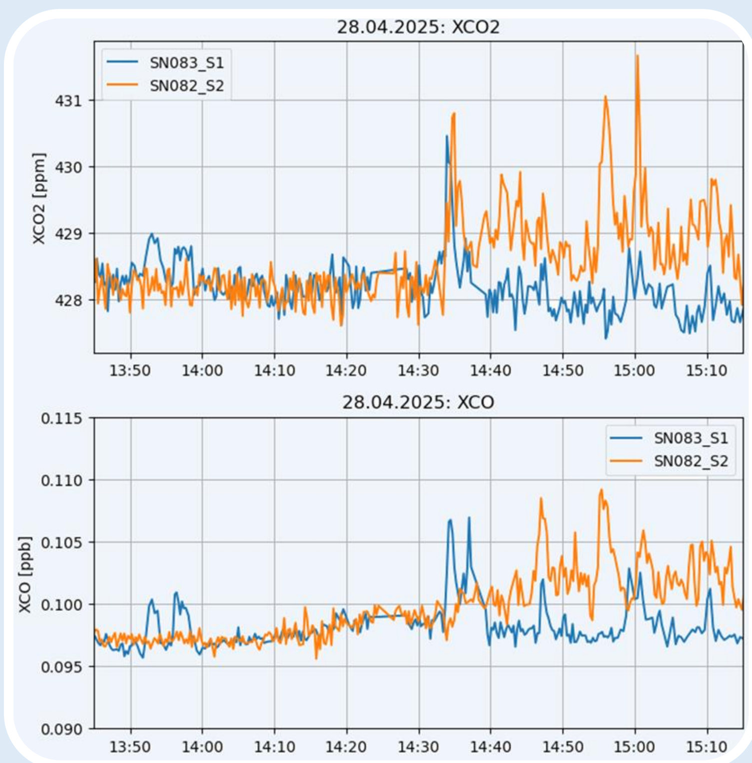
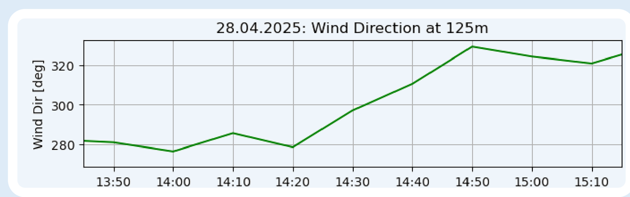


Fig. 2: Measured & simulated plume widths

Comparisons of the measured GHG abundance excess values and Gaussian model predictions, which are driven by atmospheric stability, wind direction and wind speed measurements, reveal large discrepancies, preventing reliable direct emission estimates. Using intervals where DOAS data are available, the model can be partially constrained. However, plume height corrections remain unaccounted for. Filtering scenes that are insensitive to plume height, given the viewing geometry of the instrument, allows for **preliminary emission estimates** ranging from 40 % to 179 % of inventory values, with an average of 79 ± 49 %.





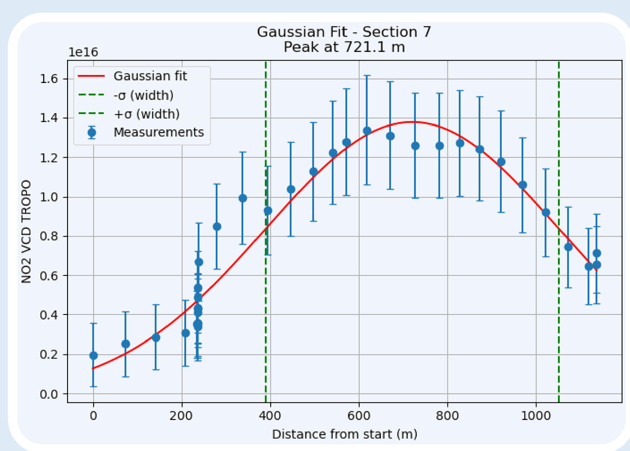


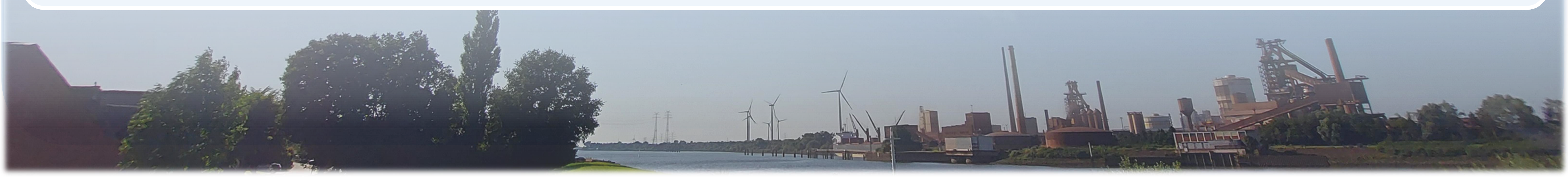
Fig. 3: Left and right up: XCO_2, XCO and wind direction measured on 28.04.25.

Right middle and down: Measurement of NO_2 in the plume and Gaussian fit of the cross section.

Conclusion

This study demonstrates the potential of combining multiple ground-based remote sensing techniques - EM27/SUN FTIR, mobile DOAS, and Wind-LIDAR – to monitor GHG emissions from large industrial sources. The CO/CO_2 emission ratio obtained from the changes in XCO_2 and XCO when the plume moves in or out of the observed columns results in a value of 3.46 ± 0.85 %, which is markedly lower than the ratio determined by satellites (6.28 ± 4.09 %) but in good agreement with the theoretical value from the emission inventory (3.33 %).

Plume observations were compared with a Gaussian dispersion model. Constraining the model by integrating real-time plume measurements yielded preliminary emission estimates ranging from 40 % to 179 % of inventory values, with an average of 79 ± 49 %. These results highlight both the promise and current limitations of ground-based remote sensing in reducing uncertainties of facility-level emission quantification. Future work should extend measurement coverage, include plume height observations, and utilise high-resolution atmospheric dispersion models to improve emission accuracy.



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The digital poster can be found here:

References

Hanna, S. R., Briggs, G. A., & Hosker, R. P. J. (1982). Handbook on atmospheric diffusion (Tech. Rep. DOE/TIC-11223). National Oceanic and Atmospheric Administration, Oak Ridge, TN, USA: Atmospheric Turbulence and Diffusion Lab. https://doi.org/10.2172/5591108

Schneising, O., Buchwitz, M., Reuter, M., Weimer, M., Bovensmann, H., Burrows, J. P., & Bösch, H. (2024). Towards a sector-specific CO/CO_2 emission ratio: Satellite-based observations of CO release from steel production in Germany. Atmospheric Chemistry and Physics, 24(13), 7609–7621. https://doi.org/10.5194/acp-24-7609-2024

Umweltbundesamt. (2022). Zentrales deutsches Portal für Emissions- und Abfalldaten. https://thru.de/

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