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Monitoring CO_2 Emission Reductions from Space: A case study on Europe's largest power plant and implications for future missions

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Canada

2017 and 2021 papers demonstrated method with OCO-2

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER

10.1002/2017GL074702

Quantifying CO_2 Emissions From Individual Power Plants From Space

Ray Nassar[1], Timothy G. Hill[2], Chris A. McLinden[3], Debra Wunch[4], Dylan B. A. Jones[4], and David Crisp[5]

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Key Points:
- The combustion of coal for electricity generation accounts for more than 40% of global anthropogenic CO_2 emissions
- Orbiting Carbon Observatory 2 observations can be used to quantify CO_2 emissions from individual coal power plants, in selected cases
- This work suggests that a future constellation of CO_2 imaging satellites could monitor fossil fuel power plant CO_2 emissions to support climate policy

Supporting Information:
- Supporting Information S1

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Abstract In order to bett
emissions are needed at all sp
Orbiting Carbon Observatory
show that in some cases, CO_2
individual middle- to large-siz
estimates for U.S. power plan
of the approach to internatior
of future CO_2 imaging satellite
plants to support the implem

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Check for updates

Advances in quantifying power plant CO_2 emissions with OCO-2

Ray Nassar[a,*], Jon-Paul Mastrogiacomo[b], William Bateman-Hemphill[b], Callum McCracken[b], Cameron G. MacDonald[b,1], Tim Hill[b], Christopher W. O'Dell[c], Matthäus Kiel[d], David Crisp[d]

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2006 IPCC Guidelines for National Greenhouse Gas Inventories

WMO **Intergovernmental Panel on Climate Change** UNEP

Edited by Simon Eggleston, Leandro Buendia, Kyoko Miwa, Todd Ngara and Kiyoto Tanabe

Chapter 6: Quality Assurance / Quality Control and Verification

2006

Considering the limited monitoring network currently available for many of the greenhouse gases and the resulting uncertainties in the model results, inverse modelling is not likely to be frequently applied as a verification tool of national inventories in the near future. Even the availability of satellite-borne sensors for greenhouse gas concentration measurements (see Bergamaschi *et al.*, 2004) will not fully resolve this problem, due to limitations in spatial, vertical and temporal resolution. However, there is increasing scientific recognition for the potential of these techniques for both level and trend verification of national inventories.

2019 Update

Chapter 6 contains updated guidance on quantification of emissions estimates based on atmospheric concentration measurements. … Key features of the updates include a description of the elements needed for GHG emissions inventory verification using atmospheric measurements including the role of inverse modelling and satellite observations. … OCO-2 satellite observations have shown potential for quantifying carbon dioxide emissions from large power plants (Nassar et al. 2017).

Overview of Method and Equations

- Identify background and enhancement in OCO-2 XCO_2
- Fit observed OCO-2 XCO_2 enhancements to 2D Gaussian plume model
- Optimize wind direction by iterating fit with small adjustments to wind direction to maximize correlation coefficient (R)
- Determine emission estimates, varying some parameters yielding an ensemble of estimates for quantifying uncertainties

$$V(x,y) = \frac{F}{\sqrt{2\pi}\sigma_y(x)u} e^{-\frac{1}{2}\left(\frac{y}{\sigma_y(x)}\right)^2}$$

$$\sigma_y(x) = a \cdot \left(\frac{x}{x_o}\right)^{0.894}$$

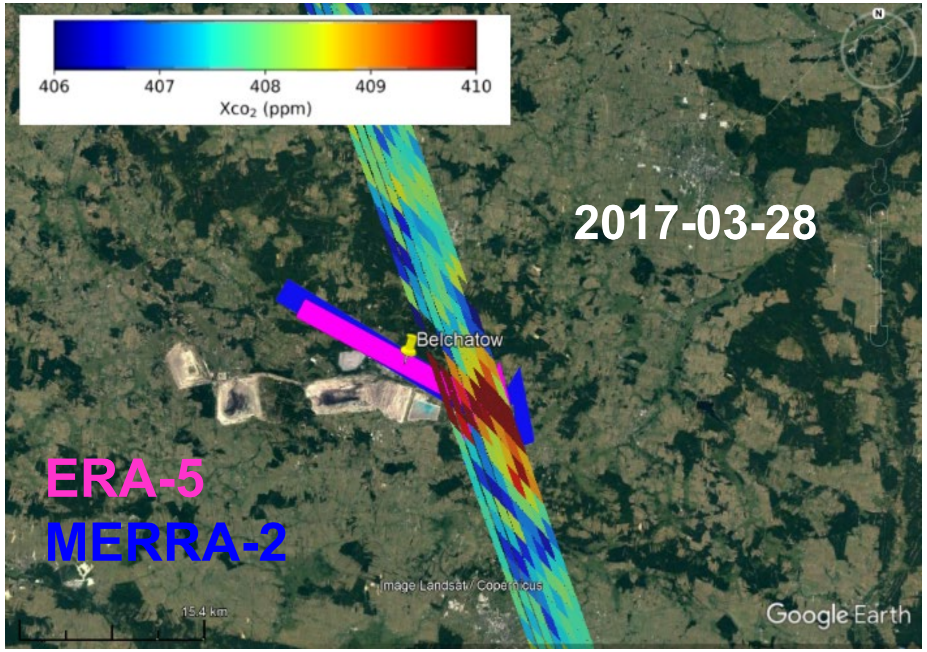
V is the CO_2 vertical column (g/m^2) downwind of the point source
x is along wind distance (m) (x_o = 1000 m is a characteristic length)
y is across wind distance (m)
F is emission rate (g/s)
u is the wind speed (m/s)
$\boldsymbol{\sigma_y}$ is the standard deviation in the wide direction (measure of the plume width) (m)
a is the atmospheric stability parameter

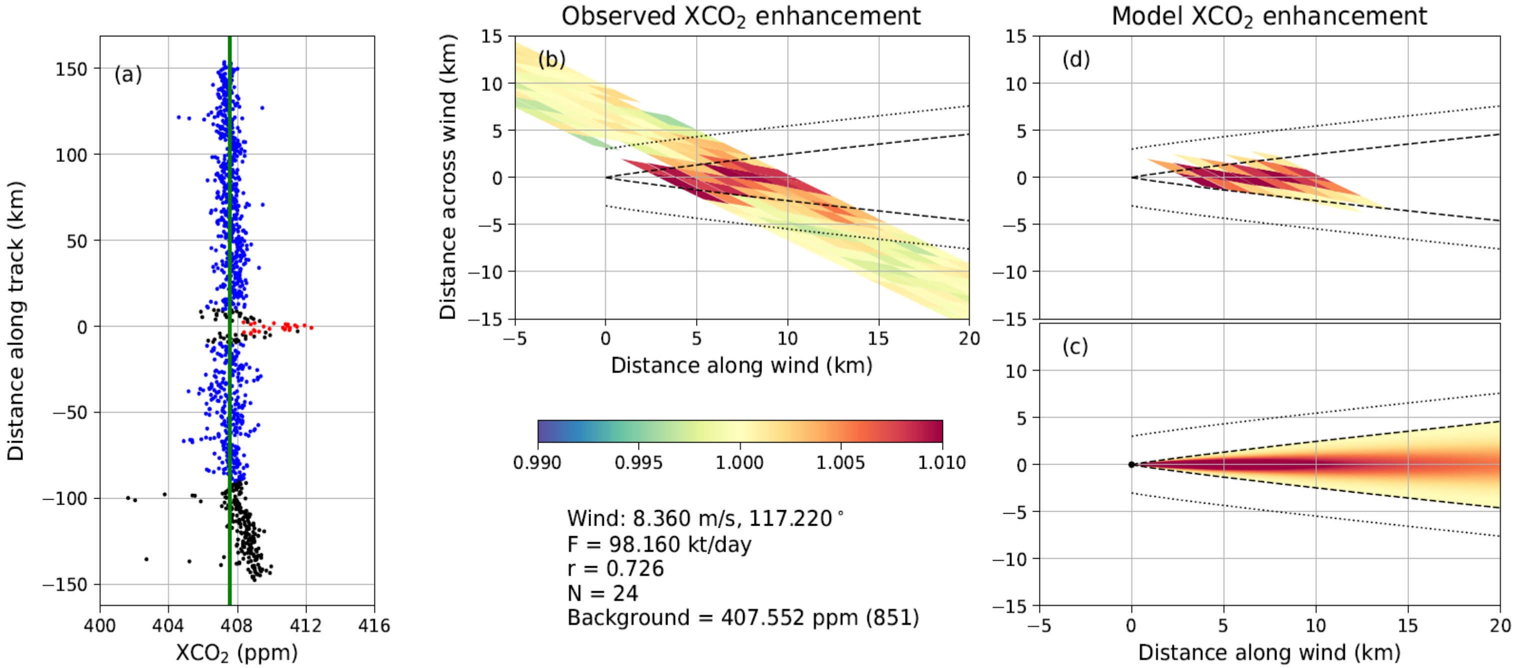
$$\varepsilon = \sqrt{{\varepsilon_w}^2 + {\varepsilon_b}^2 + {\varepsilon_e}^2 + {\varepsilon_r}^2 + {\varepsilon_s}^2}$$

Wind Background Enhancement Rise Secondary Sources

Bełchatów Power Plant

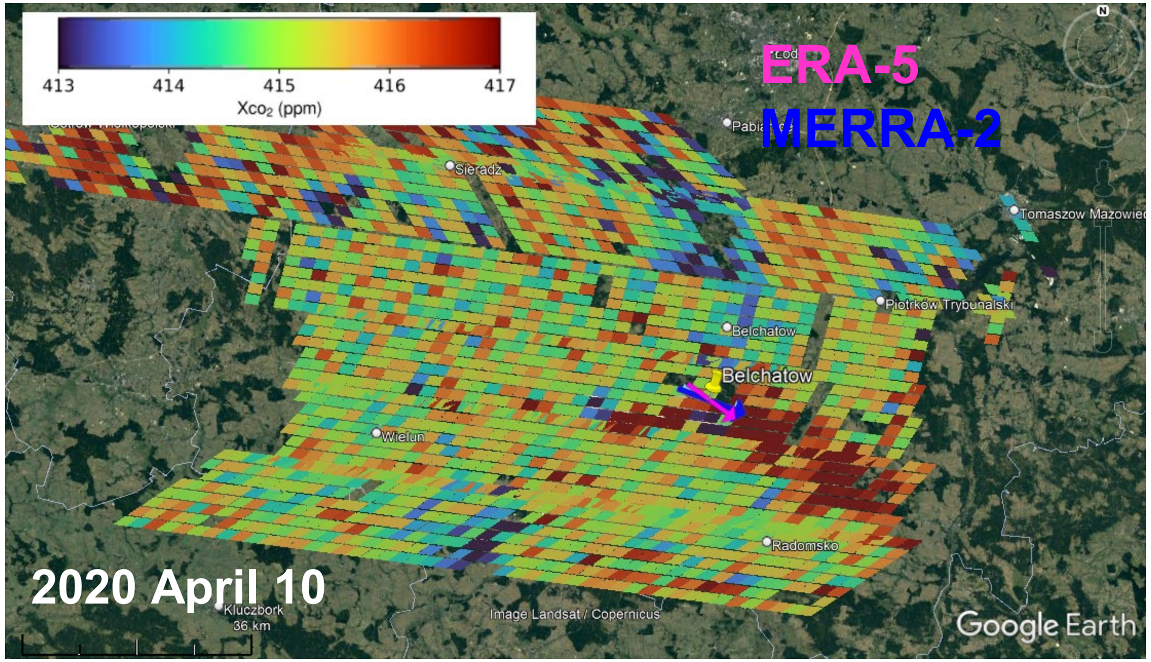
- Largest fossil fuel power plant in Europe
- 5th largest in the world (5102 MW)
- Reported emissions for 2017 are 37.6 $MtCO_2$, average of 103.0 $ktCO_2$/day

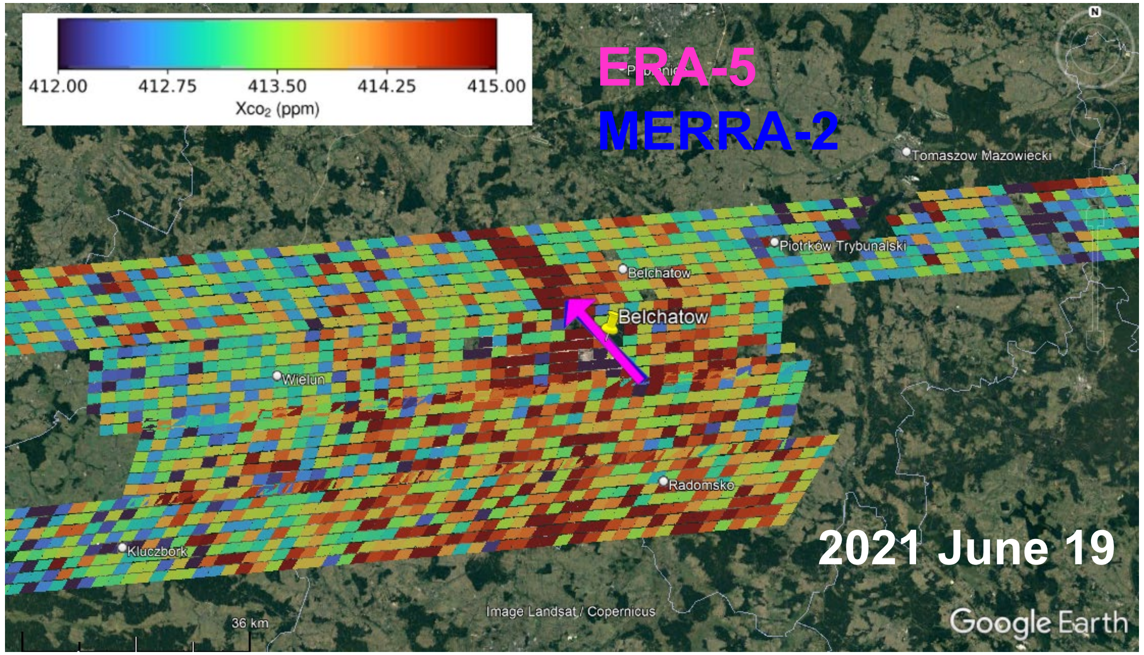




- Wind rotation of -2.0° applied, gives very good model-data correlation (R = 0.726)
- Estimate 98.2 ± 12.1 $ktCO_2$/day with ±9.6 $ktCO_2$/day due to wind speed uncertainty

Quantifying CO_2 Emission Changes at Bełchatów





- Multiple OCO-3 v10 Snapshot Area Maps (SAMs) of Bełchatów power plant in 2020-2021 now available
- We can compare our emissions estimates derived from OCO-2/OCO-3 to those expected based on power generation available from the European Network of Transmission System Operators for Electricity Transparency Framework

Quantifying CO_2 Emission Changes at Bełchatów

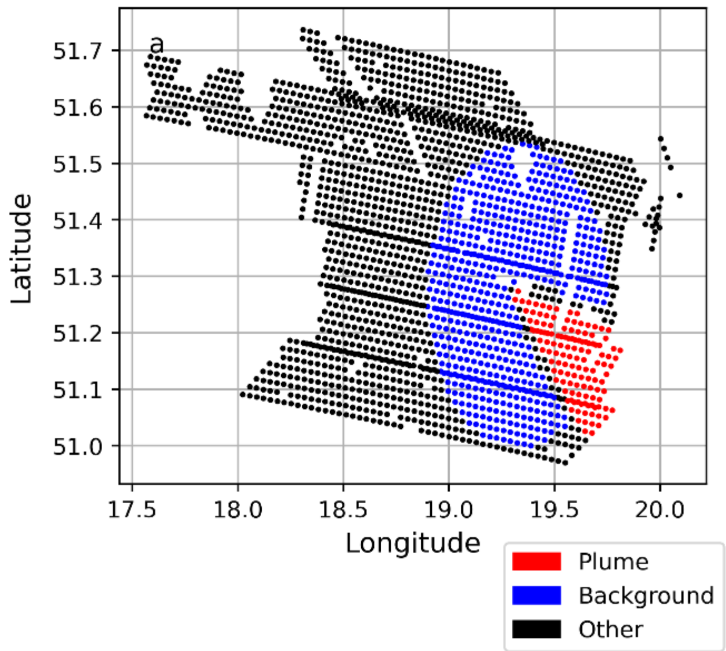
Overpass	Mission	Power Generated at overpass time (MW)*	Expected emissions ($ktCO_2$/day)	OCO mission emission estimate ($ktCO_2$/day)#	Expected & observed % change	Correlation	Footprints in plume (background)
2017-03-28	**OCO-2**	**4755**	**103.0**	**98.2 ± 11.9**	**Baseline**	**0.726**	**24 (851)**
2020-04-08	OCO-3	3615	78.3	50.5 ± 16.9	-24 / -49 %	0.636	240 (466)
2020-04-10	OCO-3	3601	78.0	81.0 ± 8.2	-24 / -18 %	0.657	129 (614)
2020-04-17	OCO-3	3230	70.0	76.3 ± 3.2	-32 / -22 %	0.332	91 (476)
2021-06-18	OCO-3	3666	79.4	101.1± 4.0	-23 / +3 %	0.715	121 (676)
2021-06-19	OCO-3	3724	80.7	79.8 ± 1.1	-22 / -19 %	0.703	39 (488)
2021-06-20	OCO-3	1971	42.7	28.0 ± 1.5	-59 / -71 %	0.544	81 (549)
2021-10-08	OCO-3	2785	60.3	58.5 ± 5.2	-41 / -40 %	0.471	115 (529)
2021-10-09	OCO-3	1784	38.6	44.7 ± 5.4	-62 / -54 %	0.280	141 (426)

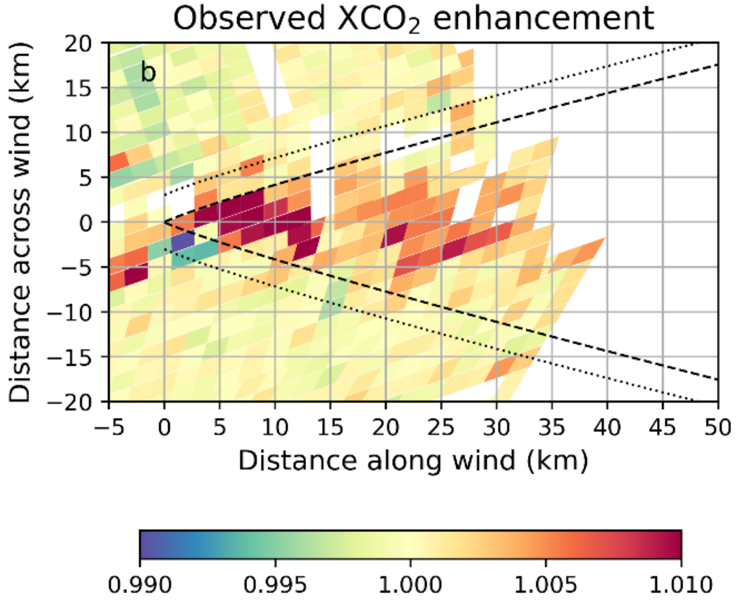
*Hourly power generation at facility unit level from entsoe

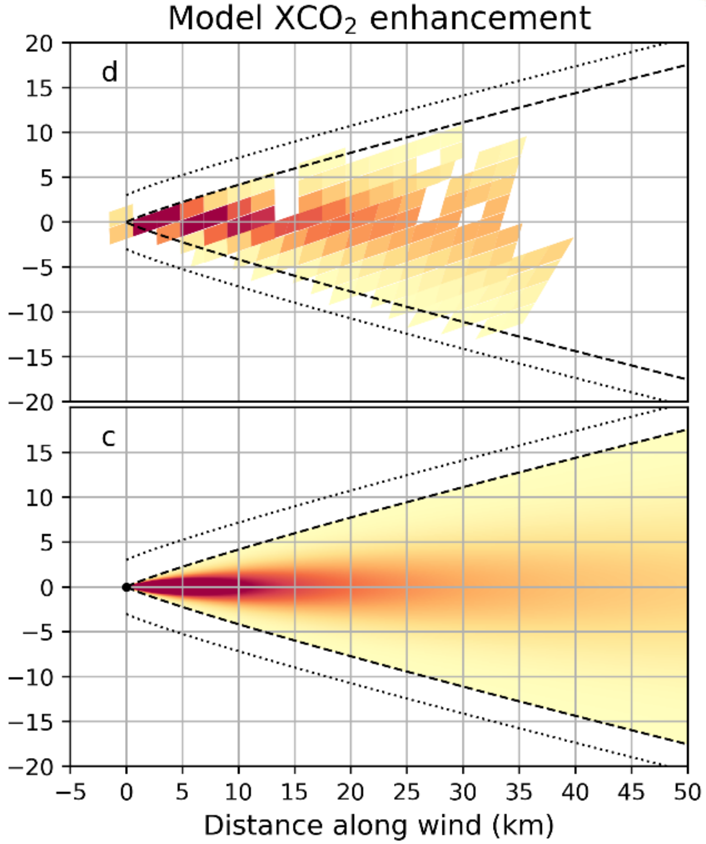
European Network of Transmission System Operators for Electricity – Transparency Platform

#OCO-3 results are still preliminary. Preliminary uncertainties shown are based only on wind speed.

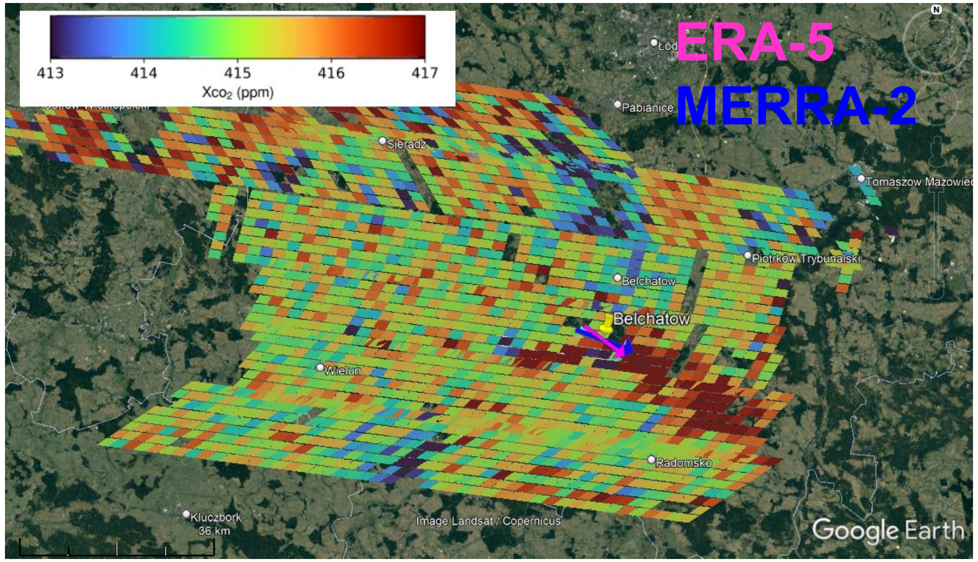
OCO-3 v10 Bełchatȯw 2020-04-10







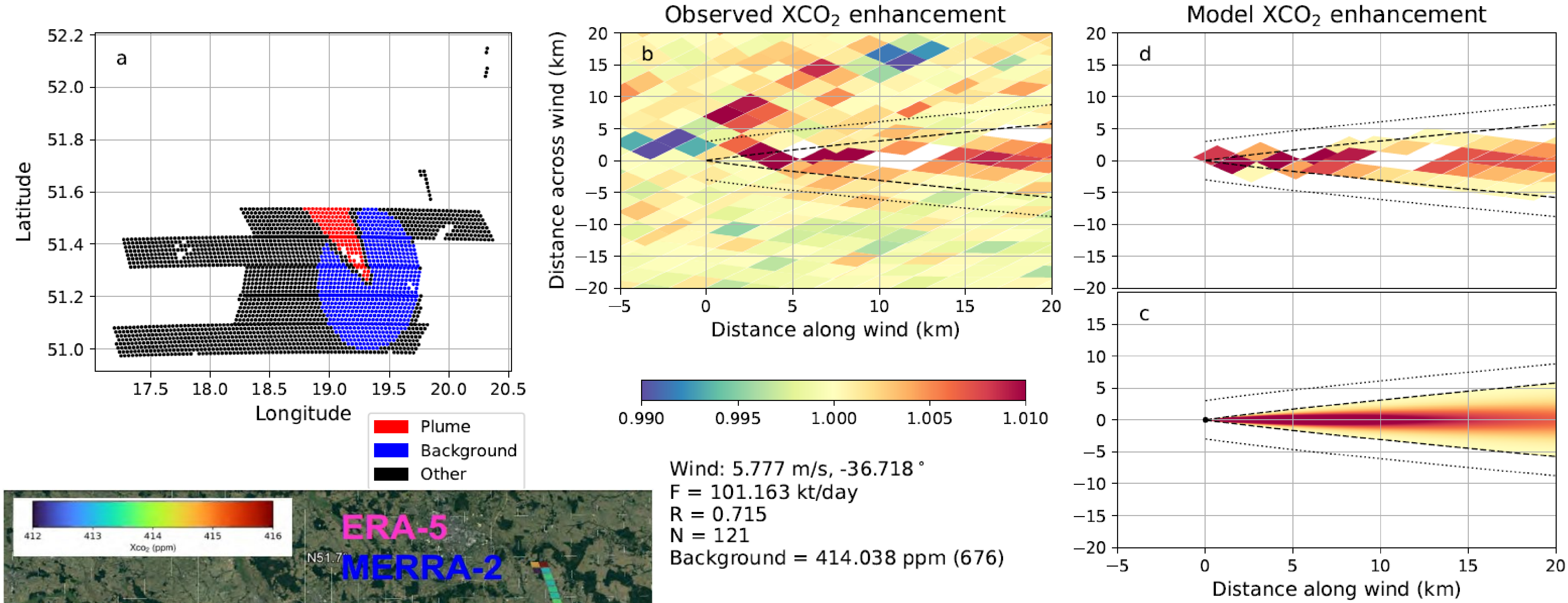
Wind: 3.857 m/s, 121.000 $^\circ$
F = 80.978 kt/day
R = 0.657
N = 129
Background = 415.150 ppm (614)

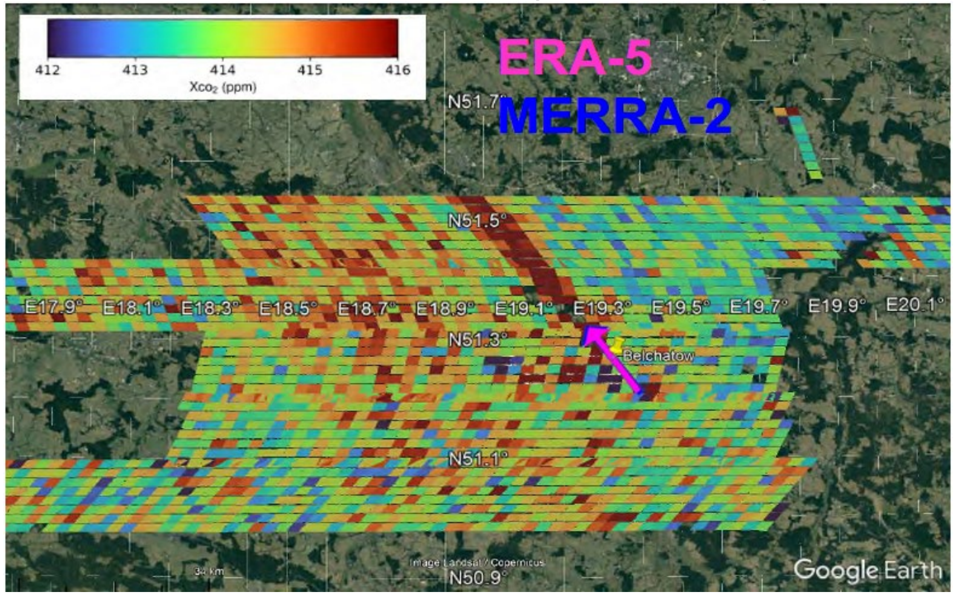


OCO-3 background is average of footprints taken within a specified radius from the source, excluding a sector corresponding to the plume and a narrow buffer zone.

Wind uncertainty is 8.2 kt/day, other uncertainties to come.
78.0 kt/day (Power Generation) **81.0±8.2** kt/day (OCO-3)

OCO-3 v10 Bełchatów 2021-06-18

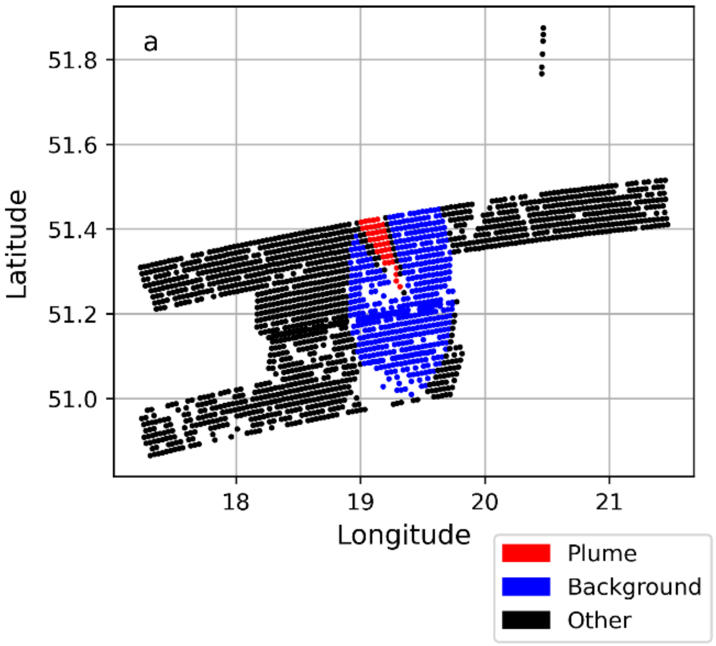


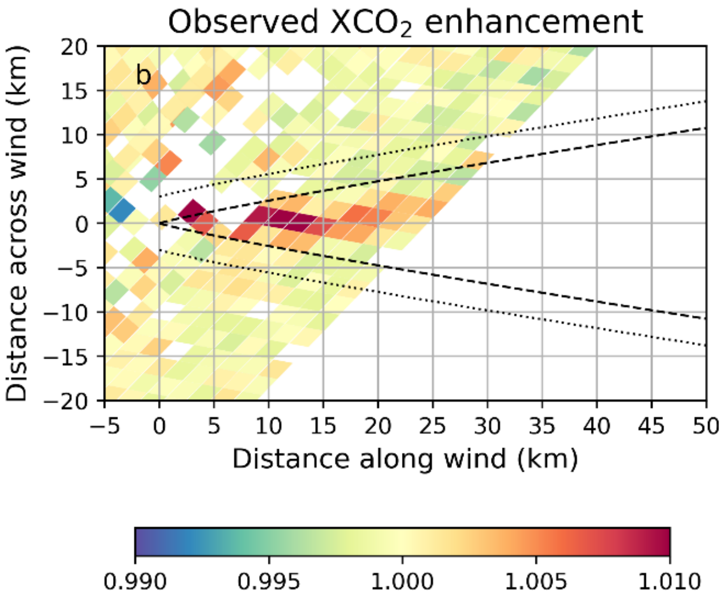


Wind uncertainty is 4.0 kt/day, other uncertainties to come.
79.4 kt/day (Power Generation) **101.1±4.0** kt/day (OCO-3).

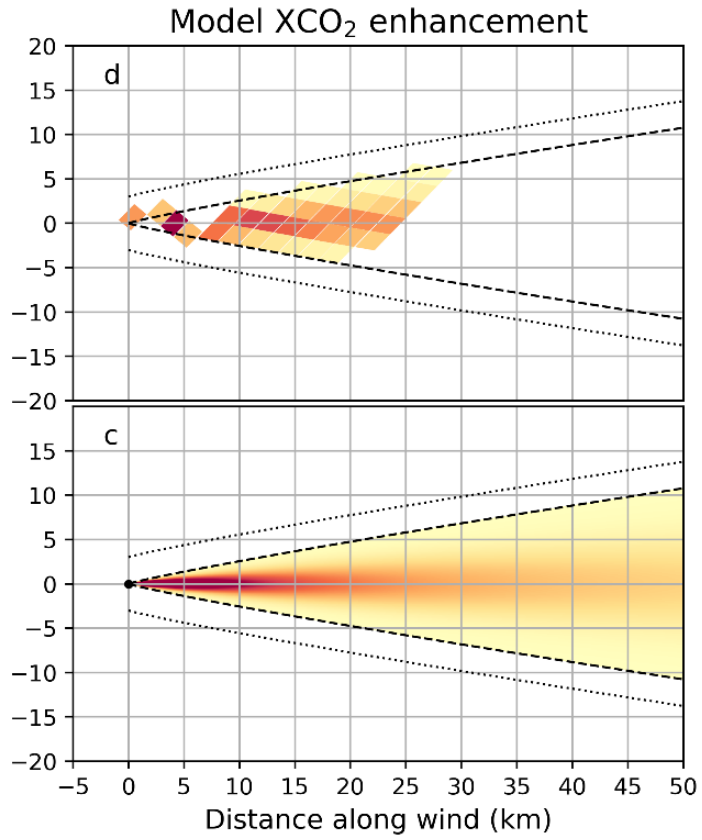
Strong symmetric plue, moderate wind speed, reasonable background and good correlation, so no obvious reason for discrepancy.

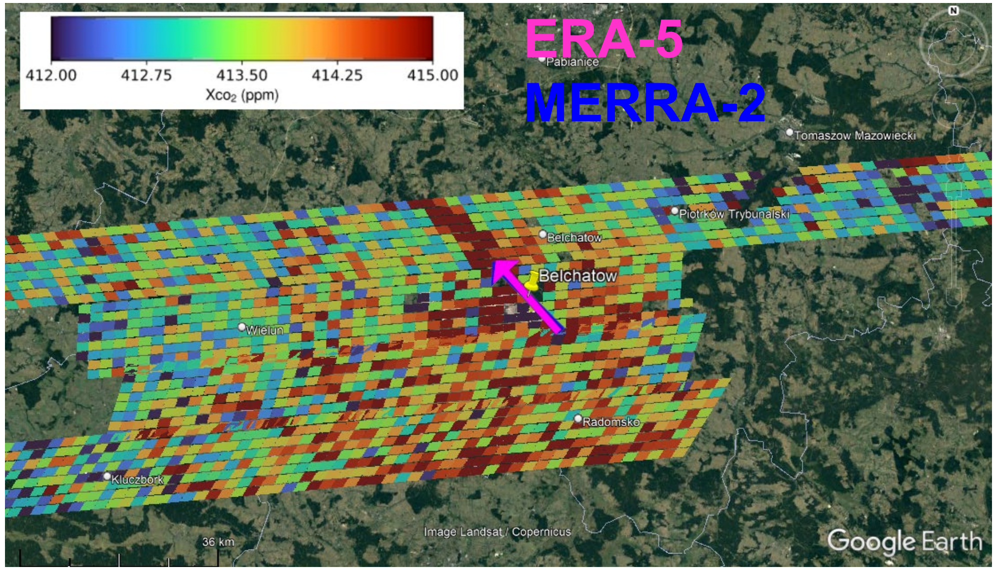
OCO-3 v10 Bełchatów 2021-06-19





Wind: 6.550 m/s, -42.639 °
F = 79.748 kt/day
R = 0.703
N = 39
Background = 413.912 ppm (488)





Wind uncertainty is 1.1 kt/day, other uncertainties to come.
80.7 kt/day (Power Generation) **79.8±1.1** kt/day (OCO-3).

Moderate wind speed, reasonable background, symmetric plume, good correlation and excellent agreement.

Quantifying CO_2 Emission Changes at Bełchatów

Overpass	Mission	Power Generated at overpass time (MW)*	Expected emissions ($ktCO_2/day$)	OCO mission emission estimate ($ktCO_2/day$)#	Expected & observed % change	Correlation	Footprints in plume (background)
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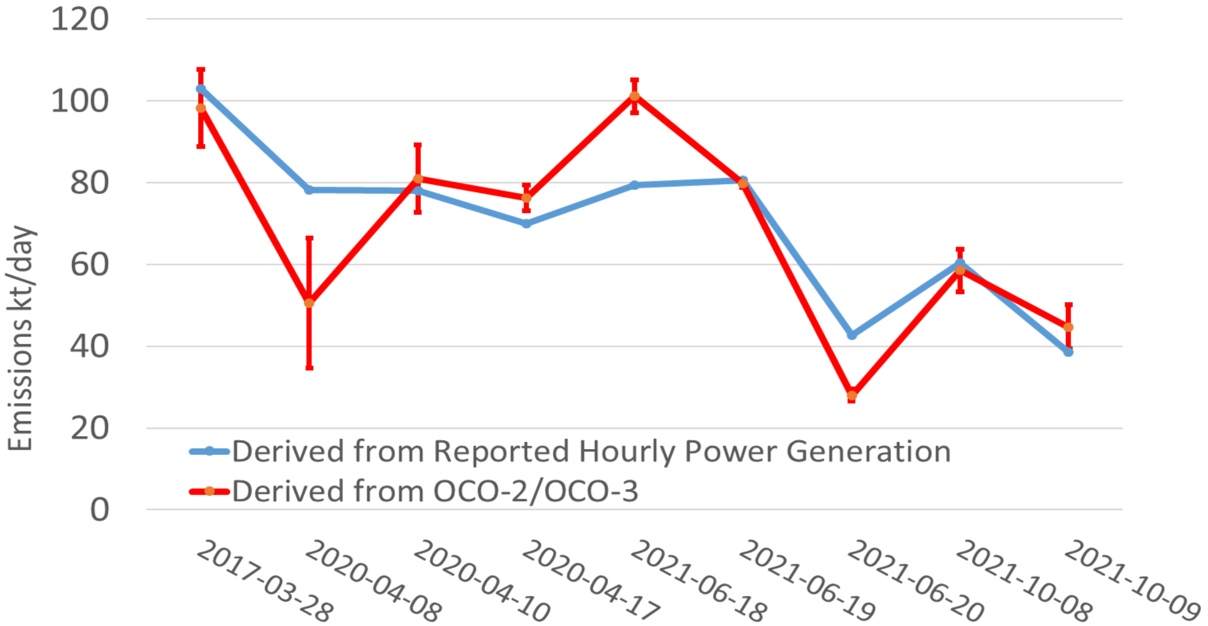


*Hourly power generation at facility unit level from entsoe

#OCO-3 results are still preliminary. Preliminary uncertainties shown are based only on wind speed.

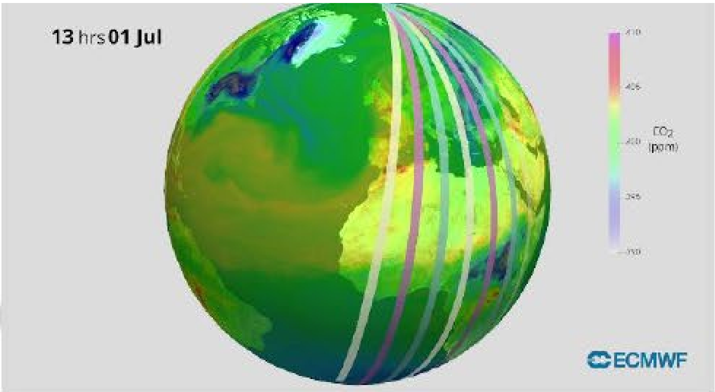
Estimated CO_2 emissions are consistent with values expected from reported power generation for ~7 of 9 points in timeseries, demonstrating the ability to quantify short-term emission changes to support policy.

Copernicus Anthropogenic CO_2 Monitoring (CO_2M) Mission

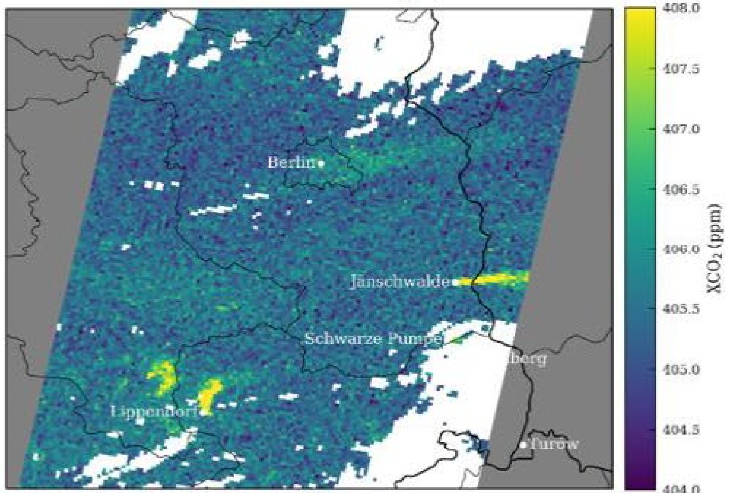
2-3 satellites to launch in 2025-2026
To observe CO_2, CH_4, NO_2 and aerosols

Mission requirements for XCO_2 & NO_2:

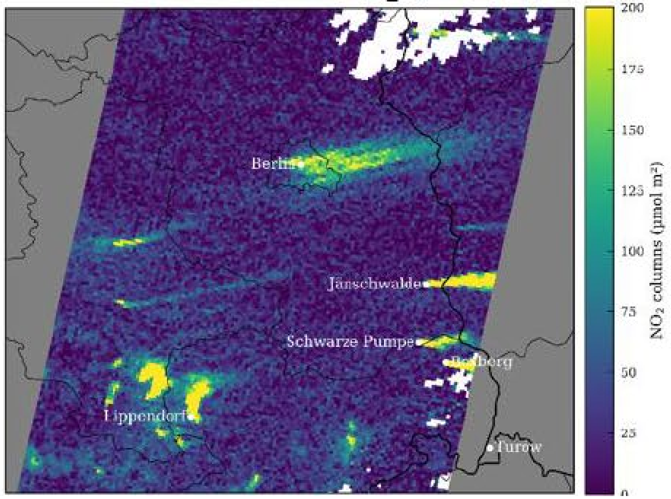
- Spatial resolution **4 km²**
- XCO_2 precision: **0.7 ppm (veg. scene, 50° SZA)**
- NO_2 precision: **$1.5 \cdot 10^{15}$ molec/cm²**
- Imaging swath **> 250 km**
- Viewing modes: **nadir (land) & sun-glint (water)**



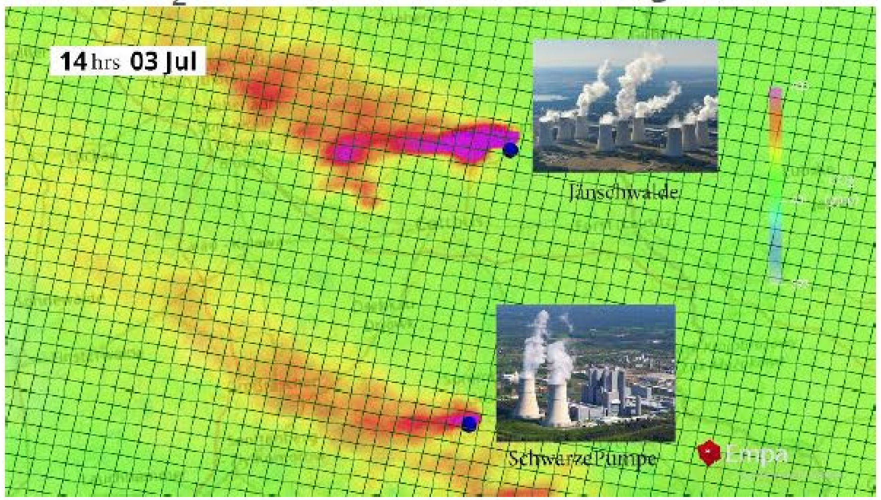
Simulated XCO_2 plumes



Simulated NO_2 plumes



CO_2 measured at 2x2 km² grid



remote sensing

2019

MDPI

Intermittency remains a challenge in upscaling to derive a fully independent annual facility-level CO_2 emissions estimate. More frequent revisit (~40/year) are needed to reduce error (<10%) in annual emissions.

Article

Pixel Size and Revisit Rate Requirements for Monitoring Power Plant CO_2 Emissions from Space

Tim Hill [1,*] and Ray Nassar [2]

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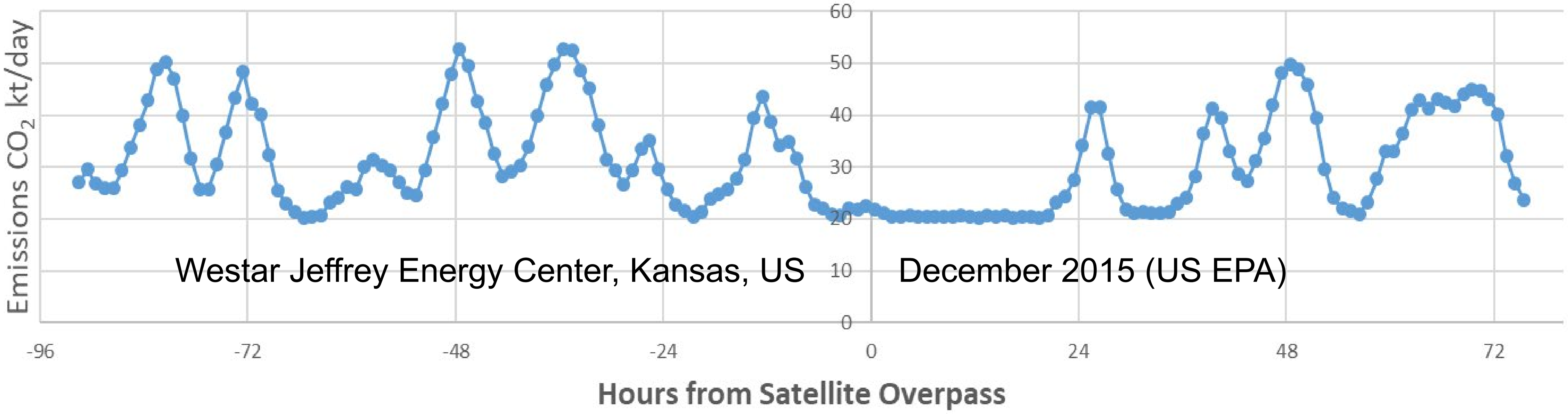
2 Climate Research Division, Environment and Climate Change Canada, Toronto, ON M3H 5T4, Canada
* Correspondence: tghill@uwaterloo.ca



Conclusions

- NASA's OCO-2 and OCO-3 have enabled quantification of CO_2 emissions from large and medium-sized power plants in select cases, but narrow swath and limited coverage were the main limitation.
- 2 CO_2M satellites will deliver ~100 times the coverage of OCO-2 along with other advantages like coincident NO_2.
- CO_2M will easily enable *verification* of facility scale CO_2 emissions when detailed reported information is available, however, a *fully independent annual* emission estimate would still require more revisits to adequately sample the intermittency and deliver acceptable annual uncertainties.
- These findings suggest a role for space-based monitoring of facility scale CO_2 emission reductions in support of the Paris Agreement and capabilities will continue to improve as the constellation of satellites expands