Environment and Climate Change Canada
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Advances in Quantifying Power Plant CO_2 Emissions from Space

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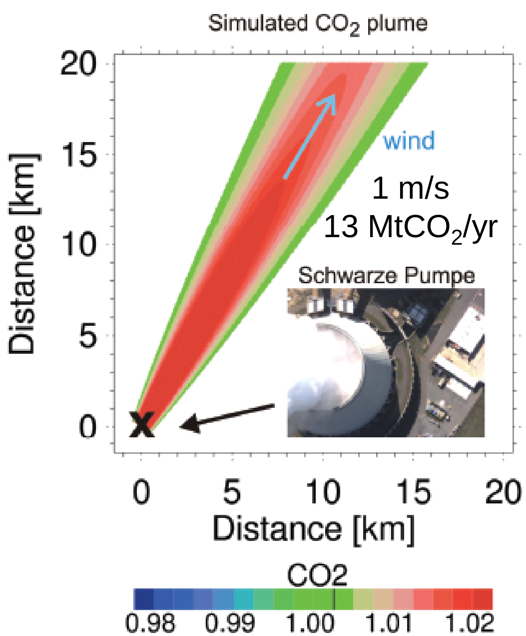
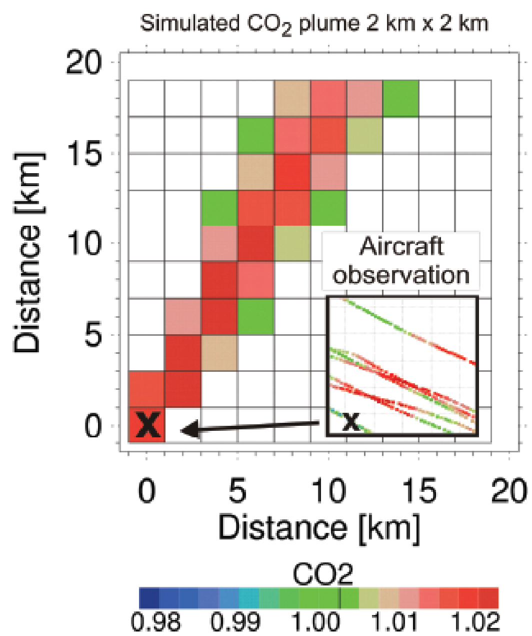
International Workshop on Greenhouse Gas Measurements from Space
Toronto, 2018-05-09

- ***CarbonSat*** was a proposed mission to monitor CO_2 and CH_4 emissions from point sources like individual power plants by ***imaging*** the plumes
- CarbonSat: 2x2 km^2 square pixels across 185-240 km swath
- OCO-2: 8 parallelogram footprints (≤1.29x2.25 km^2) across ≤ 10.3 km swath





Although OCO-2 was not designed to quantify CO_2 emissions from power plants, its observations can be used to do this in selected cases

Bovensmann et al. (2010), A remote sensing technique for global monitoring of power plant CO_2 emissions from space and related applications, Atmospheric Measurement Techniques, 3, 781-811.

AGU PUBLICATIONS

2017

Geophysical Research Letters

Quantifying CO_2 Emissions From Individual Power Plants From Space

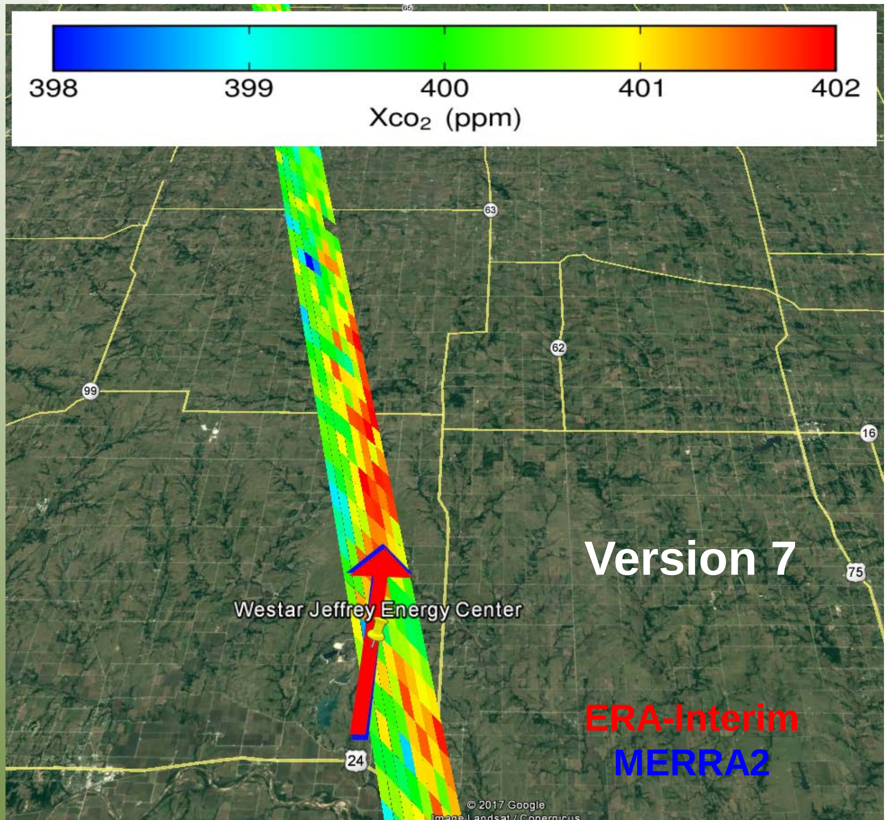
Ray Nassar[1], Timothy G. Hill[2], Chris A. McLinden[3], Debra Wunch[4], Dylan B. A. Jones[4], and David Crisp[5]

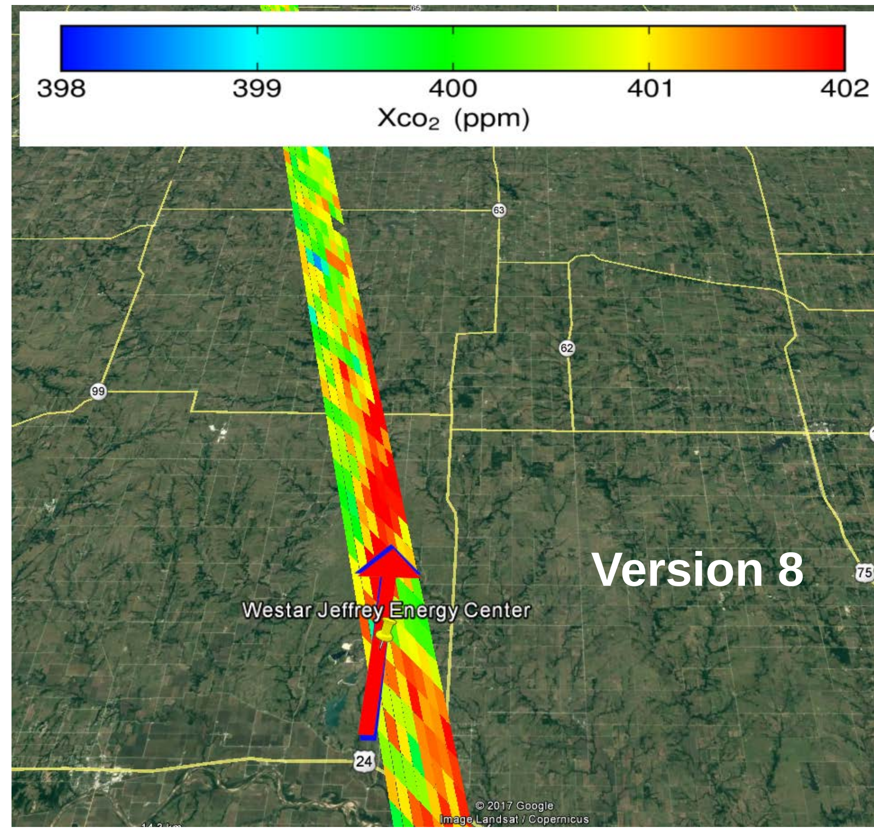
- Determine background XCO_2 and enhancement from OCO-2 data, fit observed enhancement to a model plume to scale model emissions
- Iteratively optimize wind direction, estimate uncertainty from wind speed, background ensemble, enhancement ensemble and secondary sources
- U.S. power plant estimates within 1%, 4%, 17% of EPA daily emissions
- Method applied to power plants in India and South Africa
- This work affirms that a future constellation of CO_2 imaging satellites could monitor fossil fuel power plant CO_2 in support of climate policy

New work:

- Use of OCO-2 v8 data longer time series, new power plants
- Theoretical study on footprint size, statistical study on revisit rates

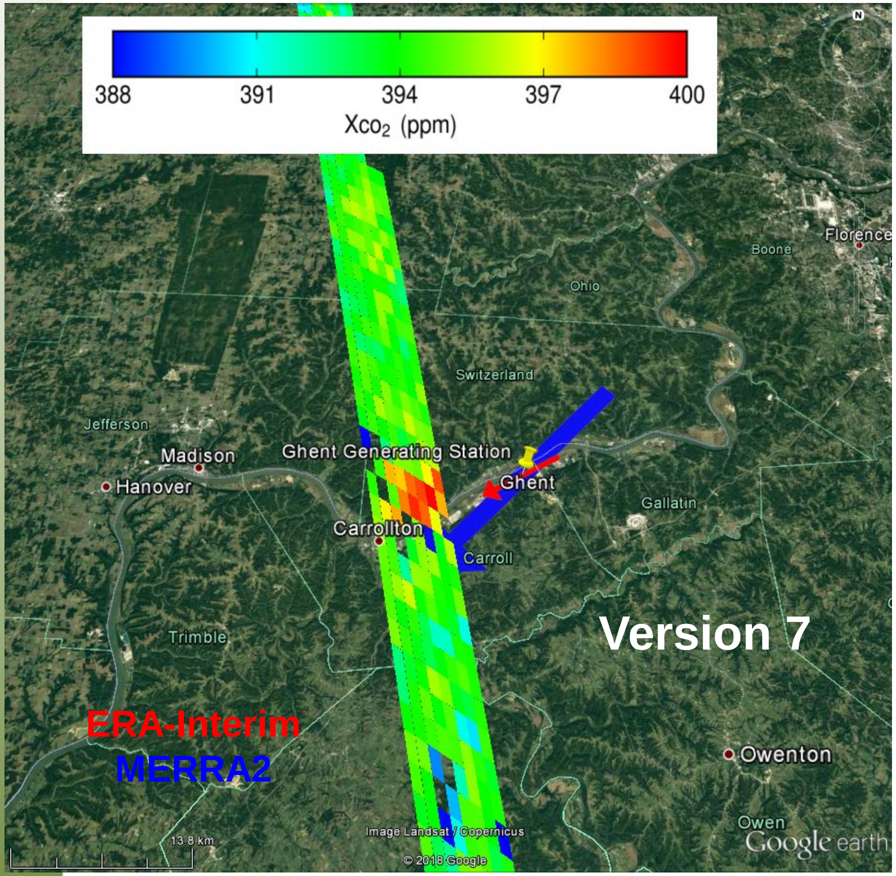
Westar Jeffrey Energy Center (Kansas) OCO-2 Version 7 vs. Version 8

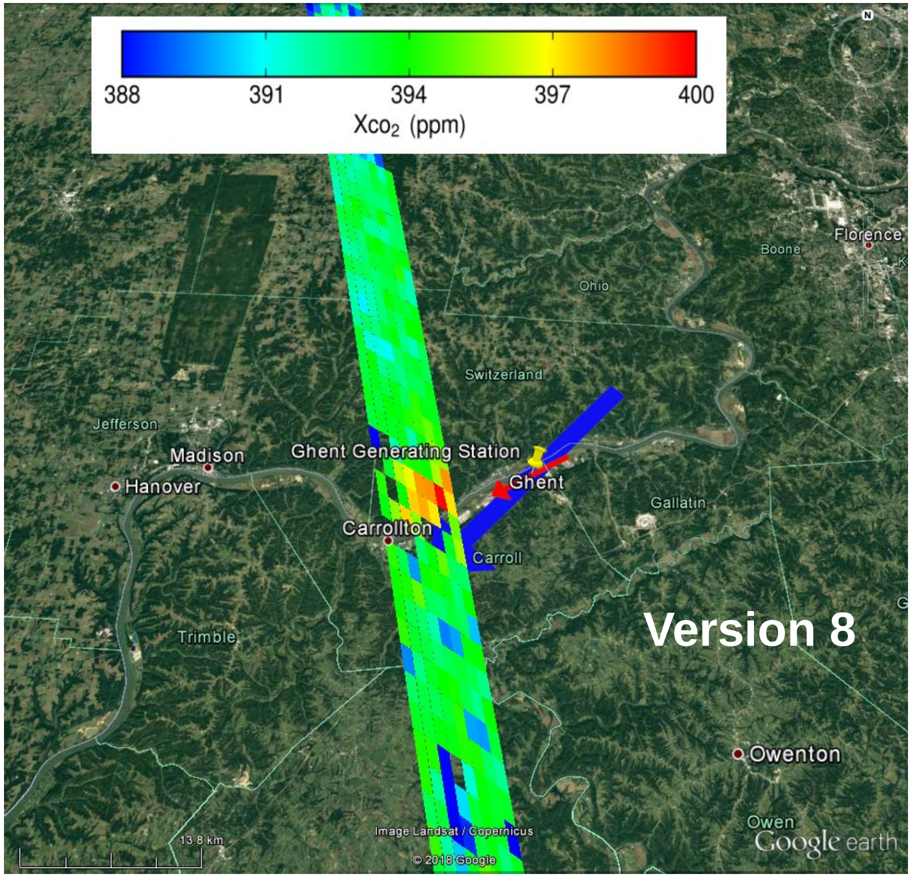




Faint signal (V7) due to strong wind (~11 m/s) is more evident in V8, but also an unexplained feature to the south and systematically higher XCO_2 overall

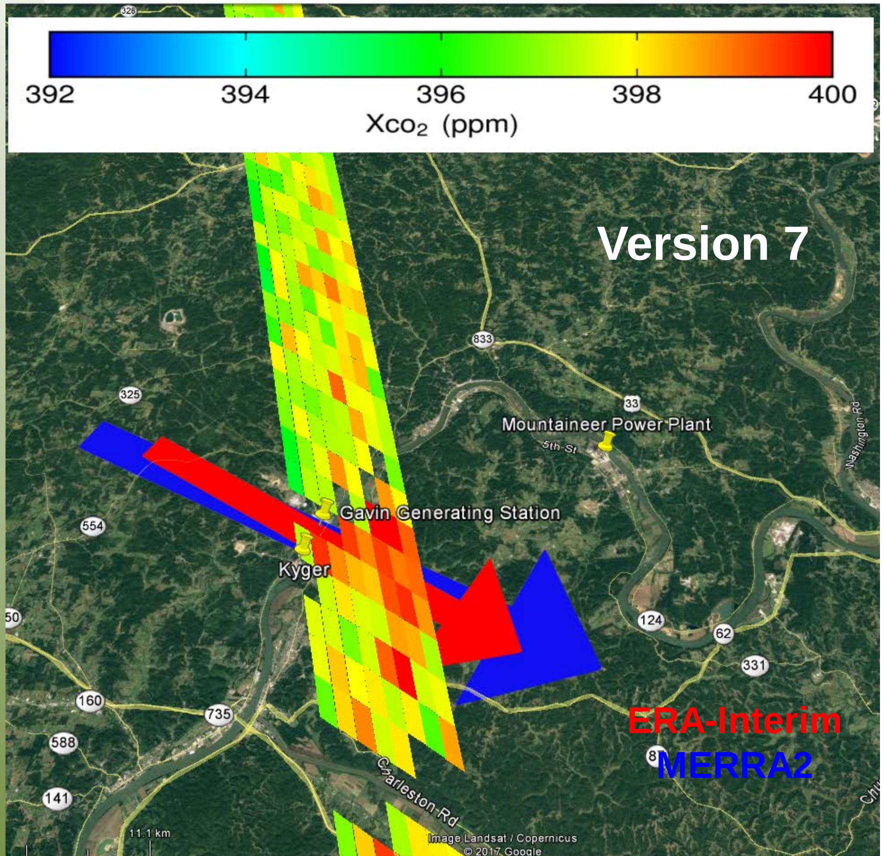
Ghent Generating Station (Kentucky): OCO-2 V7 vs. V8

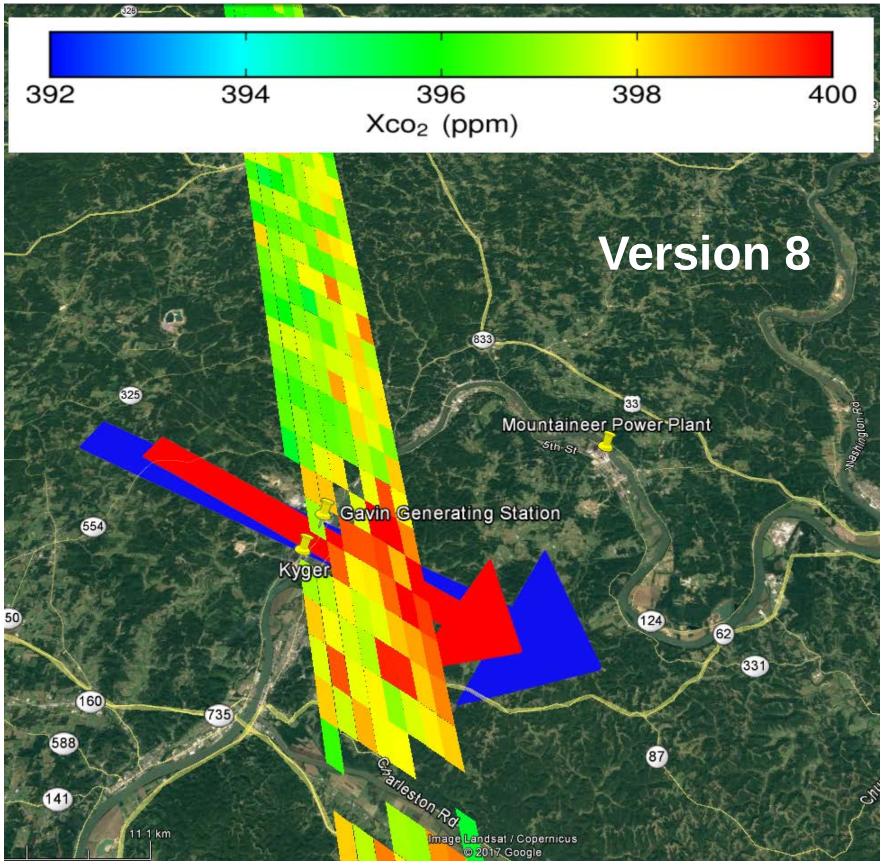




Enhancement is slightly less evident in V8.
Systematically lower overall.

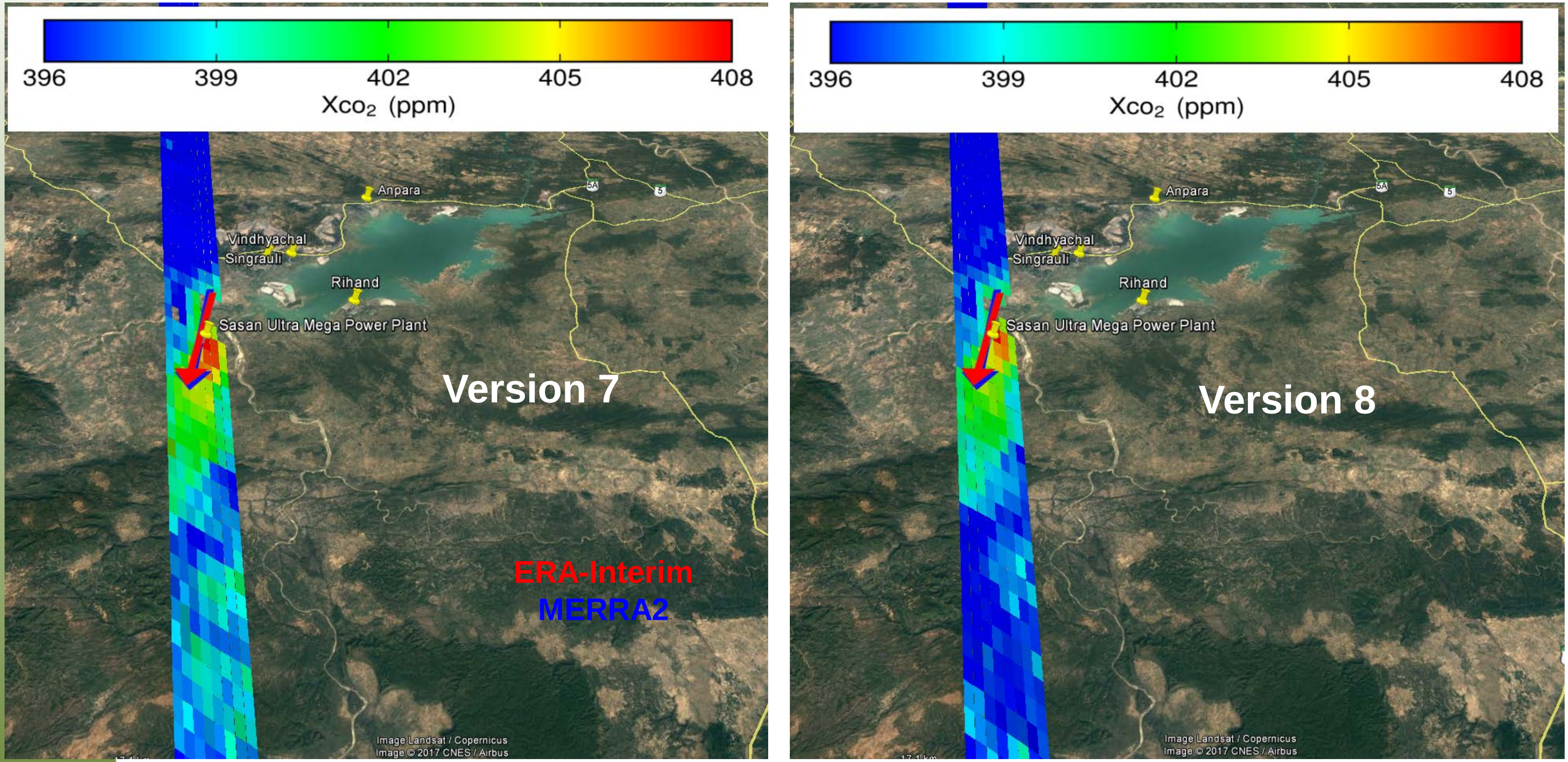
J.M. Gavin & Kyger Creek (Ohio): OCO-2 V7 vs. V8





V7 and V8 look roughly similar.

Sasan Ultra Mega Power Plant (India) OCO-2 V7 vs. V8



Very similar plume in both versions, but cleaner region in V8 to the south

Emission Estimate Summary V7 & V8

	Date	Reported Emissions	V7 Emissions	V8 Emissions	V7 R	V8 R
Westar	2015-12-04	26.67 kt/day[a]	31.21±3.71	27.51±3.33	0.468	0.538
Ghent	2015-08-13	29.17 kt/day[a]	29.46±15.58	29.79±15.66	0.707	0.732
Gavin+Kyger	2015-07-30	50.54 kt/day[a]	48.66±10.37	50.02±8.04	0.688	0.511
Sasan	2014-10-23	60.23 kt/day[b]	67.93±9.98	64.30±9.42	0.695	0.703

[a] EPA reported daily emissions from Air Markets website
[b] Daily mean calculated from Sasan CDM application annual value with 5 of 6 units commissioned by March 2015

- Version 8 U.S. Estimates are closer to EPA values
- Sasan (India) results are similar, although some difference in plume model parameters were used with v8 data. Likely that both v7 and v8 values are underestimates, with potential for better values with a more sophisticated modeling approach, to be explored in the future
- Matimba (South Africa) not shown, still being investigated for v8

Bełchatów Power Plant (Poland)

- One of the largest fossil fuel power plants in the world and largest in Europe, supplies 20% of Poland’s electricity
- Coal (lignite) burning, capacity of 5472 MW (March 2017)
- Spans a large area with stack height of 300 m
- Had planned to implement Carbon Capture & Storage (CCS) but cancelled when they did not get EU subsidy

- Some different estimates for annual emissions online:

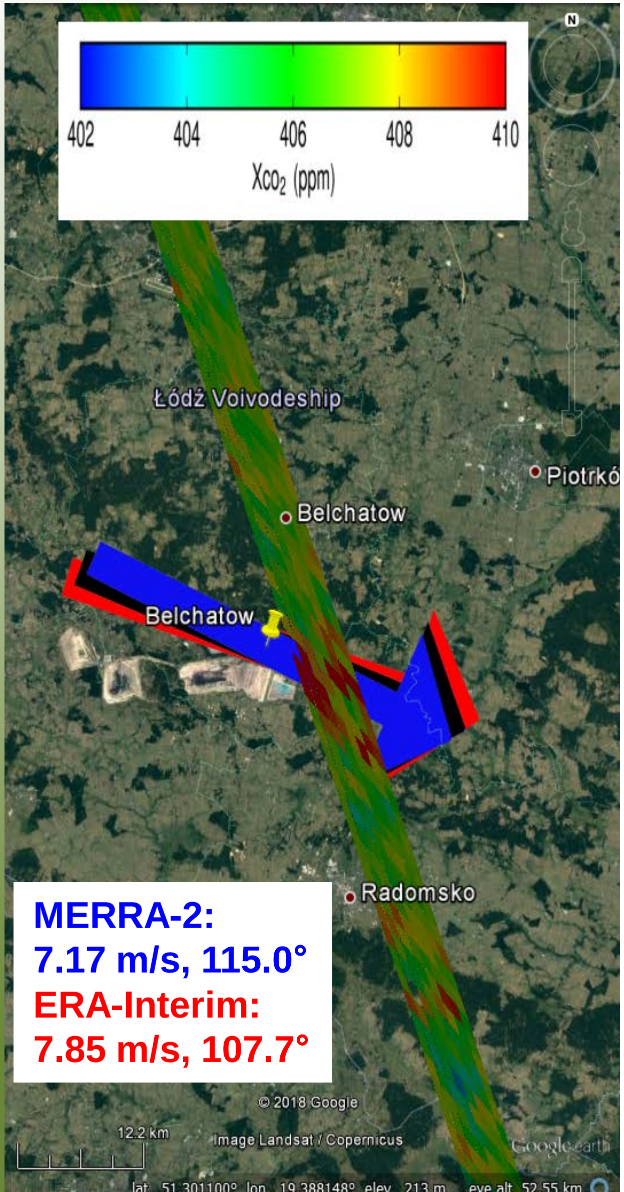
  - 26.4 $MtCO_2$/yr = mean 72.3 kt/day

(CARMA future, http://carma.org/plant/detail/3873)

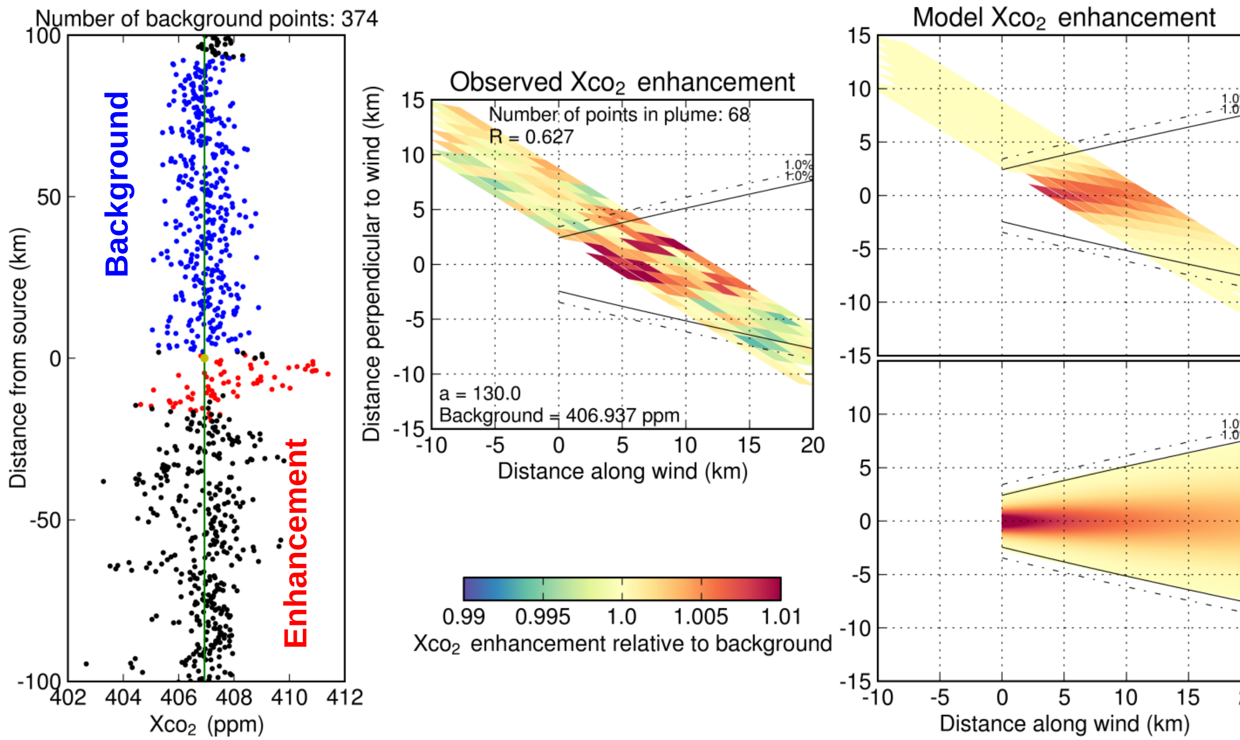
  - 37.2 $MtCO_2$/yr = mean 102 kt/day

(European Commission for 2013 and Climate Action Network - Europe report 2014)

Bełchatów Power Plant (Poland)



March 2017. Wind 7.49 m/s, 125.0°

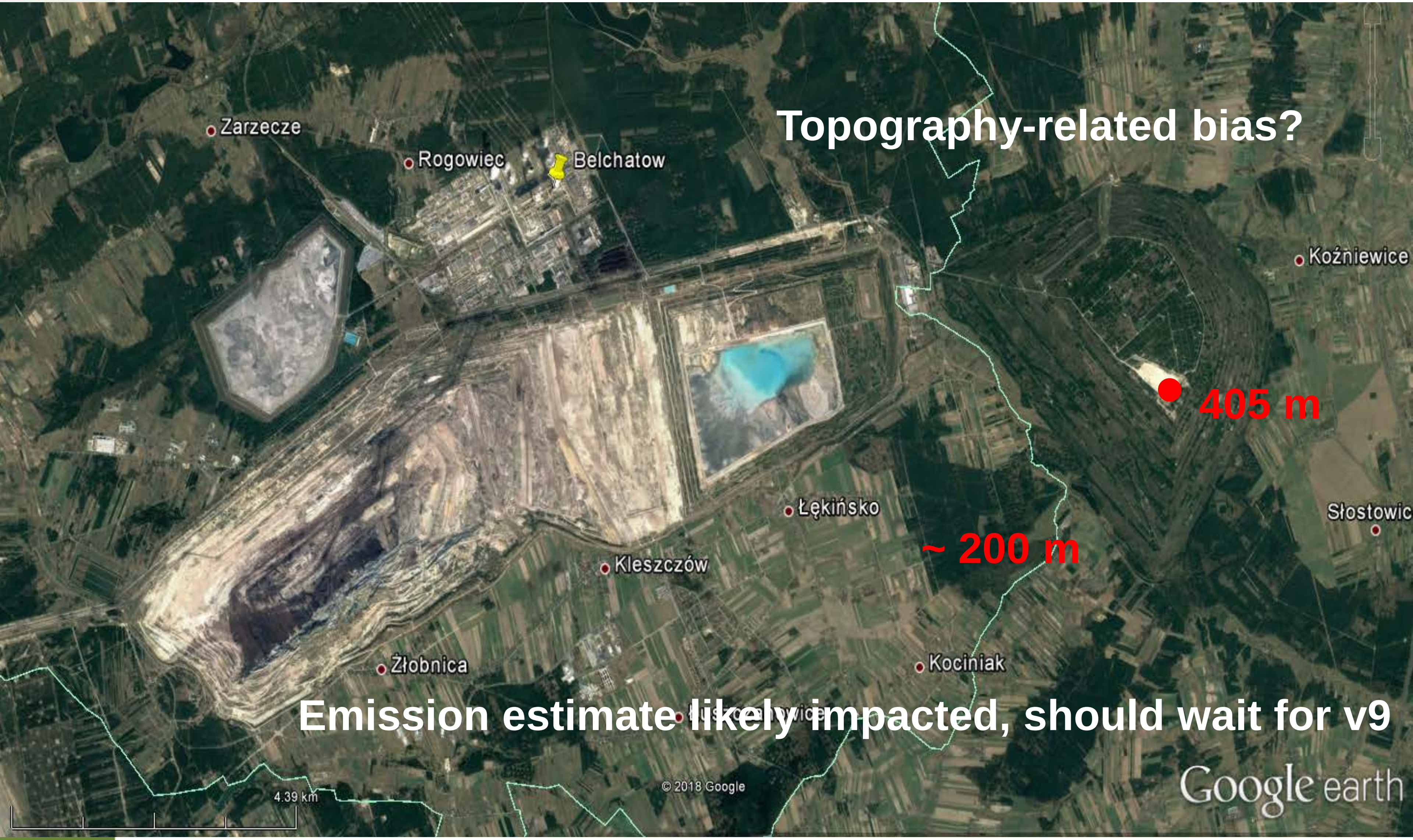


Wind rotation of 13.8° and y_o ≈ 800 m improves R from 0.40 to 0.63

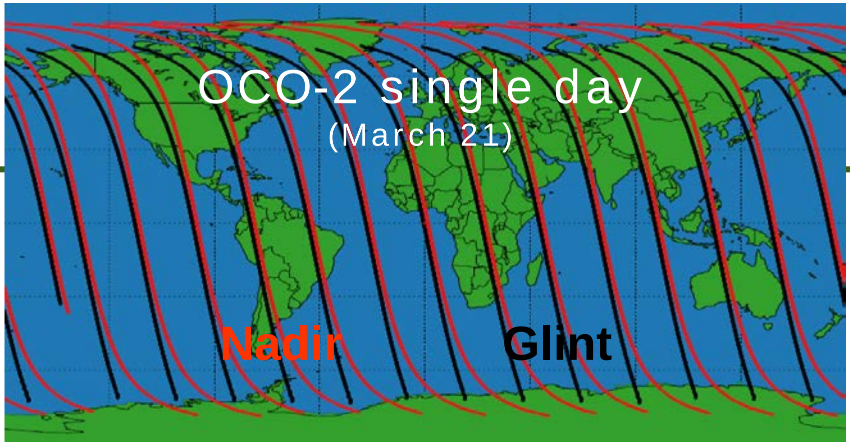
Estimated Emissions: *103.1±10.6* ktCO$_2$/day
Error budget: wind speed: ±2.4 kt/day
background ensemble: ±2.1 kt/day
enhancement ensemble: ±10.2 kt/day

Very sensitive to y_o selection, giving values below CARMA (72.3 kt/day) and above European Commission (102 kt/day)

Bełchatów Power Plant (Poland)



Coverage Estimates



Surface area of Earth: 510 million km^2

Circumference of Earth: 40,000 km

OCO-2

- Assuming mean swath of 6 km (range ~2-10 km), could image up to 120,000 km^2 per orbit (dayside only) or ~52 million km^2 in 30 days or 10% of Earth surface
- More than 90% of this is lost due to clouds, leaving < 1% of Earth surface covered per month

Copernicus CO_2 Sentinel

- 200 km swath would cover up to ~33% of the Earth per month per satellite

Satellite CO_2 Lidar

- 100 m swath (day/night or dawn/dusk) and 25% cloud free data gives ~0.088% of Earth surface per month

Greater coverage and/or targeting capabilities are required.

What revisit rate do we need?

- Quantifying annual emissions requires multiple revisits to deal with seasonal cycle and day-to-day variability
- Investigated variability of 29 large US power plants with EPA data
- If variability can be approximated as Gaussian, can relate the uncertainty of single overpass emission estimate to an annual estimate at 95% confidence interval and determine how many overpasses we need for a given accuracy:

$$\sigma = \sqrt{s^2 + \varepsilon_{est}^2}, \quad \delta = 1.96\frac{\sigma}{\sqrt{n}} \text{ and } \quad n \approx 4\left(\frac{\sigma}{\delta}\right)^2$$

n is number of samples, $\bar{y}$ is the mean, δ is width of the distribution, $\bar{y} \pm \delta\bar{y}$ is confidence interval, σ is standard deviation, ε_{est} is daily uncertainty:

- If 10% uncertainty on single overpass, need ~34 overpasses for annual emissions to 10%
- If 15% uncertainty on single overpass, need ~44 overpasses for annual emissions to 10%

Nassar and Hill (in prep)

Summary and Conclusions

- Power plant CO_2 emission estimates from Nassar et al. (2017) mostly improve with change from OCO-2 version 7 to 8, although Sasan emission estimates are probably too low (both versions), Matimba still being investigated, both could benefit from exploring other modeling approaches

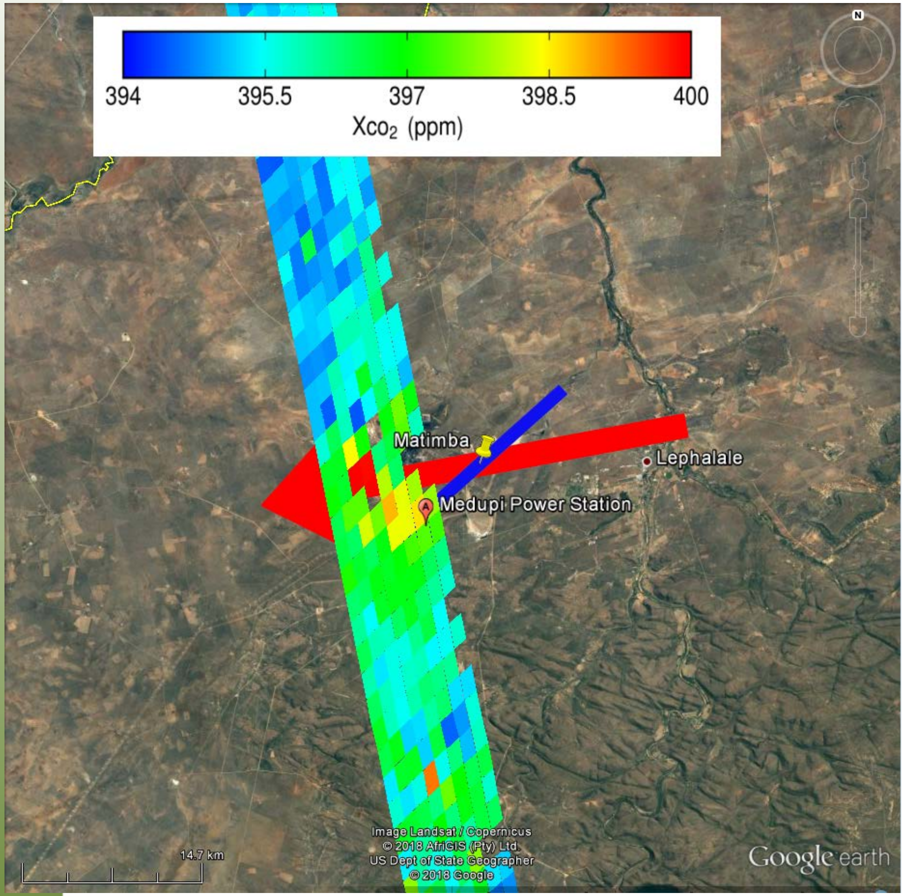
- Preliminary estimate for Bełchatów with v8, but do not trust, need v9

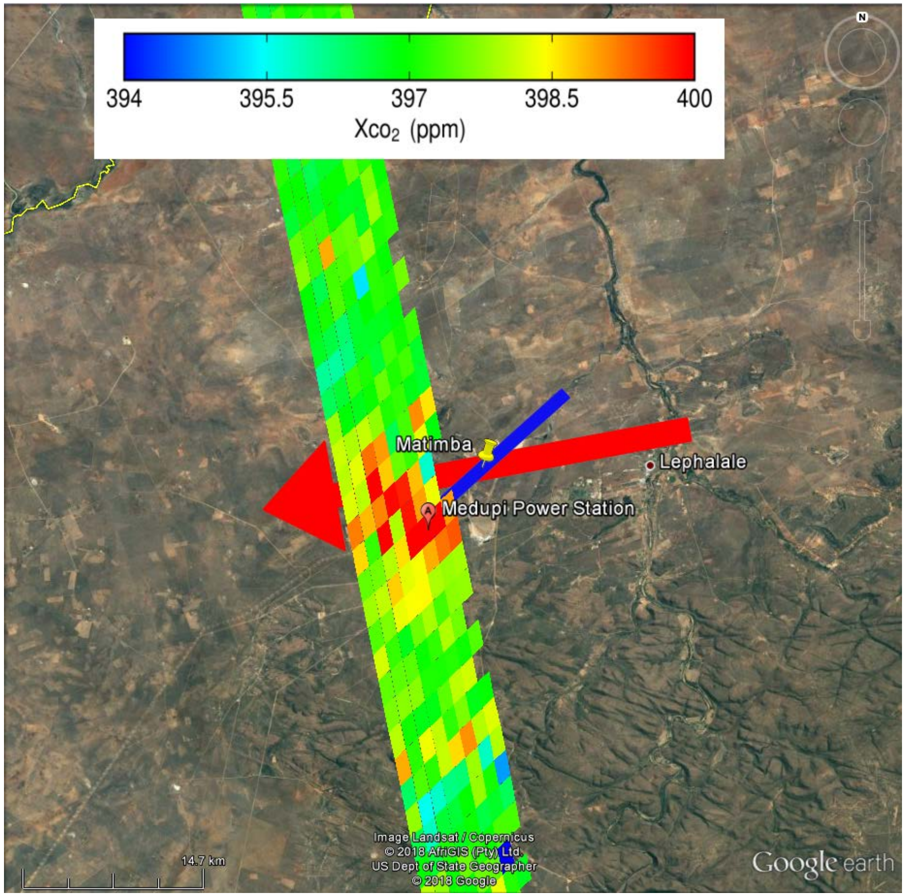
- Number of overpasses required to quantify annual emissions with a given threshold accuracy can be estimated suggesting ~34 overpasses are needed to get emissions with 10% accuracy if single overpass gives 10%

- Greater coverage and/or targeting capabilities are required for ‘Monitoring’ which is expected from future missions

Extra Slide

Matimba Power Station (South Africa) OCO-2 V7 vs. V8





Extra Slide

Sasan Ultra Mega Power Plant (v8)