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A methodology to constrain carbon dioxide emissions from coal-fired power plants using satellite observations of co-emitted nitrogen dioxide

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Text S1. Uncertainties

The uncertainty analysis is similar to the procedure described in our previous work (Liu et al., 2016), based on the fit performance and the dependencies on the a priori settings as determined in sensitivity studies. We report the derived uncertainties as a 95% confidence interval (CI). Here we briefly list the sources of uncertainties and how they are quantified. Further details are provided in Section 3 of the Supplement of Liu et al. (2016). In summary, we conclude that:

- *Choice of integration and fit intervals:* Uncertainties arising from the choice of integration and fit intervals are about 10% for the lifetime and 20% for the total NO_2 mass, respectively, based on our sensitivity analysis by changing integration and fit intervals.
- *Fit errors:* The fit errors expressed as 95% confidence interval (CI) are derived from the least-squares fit routine directly for individual sources. They are typically on the order of 10% for both lifetime and total NO_2 mass, both of which are propagated into the uncertainty of $E_{NO_x}^{Sat}$. In addition, the standard deviation of fitted lifetimes for all wind direction sectors is regarded as a measure of uncertainty to reflect the reliability of lifetimes, which is 20% on average for all power plants.
- *Wind fields:* The uncertainty associated with the wind data is 30%. The choice of wind layer height and the uncertainties of wind fields themselves contribute to the overall uncertainty.
- The derived NO_x emissions are affected by the uncertainty of the NO_2 tropospheric VCDs (~30%) and the NO_x/NO_2 ratio (~20%).
- Effects of a possible systematic change of NO_2 tropospheric VCDs from calm to windy conditions result in an uncertainty of ~10%.
- $ratio_{regressed}^{CEMS}$ contributes to an uncertainty of 15%.
- For power plants with post-combustion NO_x control devices, an additional uncertainty of 20% comes from the predicted NO_x removal efficiency of the devices.

The uncertainties of each contributor for individual power plants are listed in Table S2. We assume that their contributions to the total uncertainty are independent and define the total uncertainty as the root of the quadratic sum of the aforementioned contributions.

Name	Lat	Lon	Lifetime (h)			Mass (10^{28} molec)										
			Value	Num[a]	SD[a]	2006*	2007*	2008*	2009*	2010*	2011*	2012*	2013*	2014*	2015*	2016*
Big Stone	45.3	-96.5	3.2	3	1.0	3.4	4.0	-999	5.1	-999	-999	2.1	-999	2.4	1.8	-999
Colstrip	45.9	-106.6	-999	0	0.0	5.7	5.1	3.9	3.5	2.4	2.4	1.9	2.6	2.7	-999	-999
Craig	40.5	-107.6	-999	0	0.0	5.6	5.7	4.4	4.6	4.6	4.7	3.7	4.3	4.0	-999	-999
Crystal River	29.0	-82.7	2.1	3	0.4	11.1	10.2	-999	7.9	5.9	4.7	3.9	3.7	8.2	9.0	10.0
Four Corners & San Juan	36.7	-108.5	2.7	2	0.1	28.1	26.7	25.2	19.3	18.3	17.4	16.7	14.9	11.7	10.1	9.4
George Neal	42.3	-96.4	3.4	1	0.0	6.6	4.4	3.6	2.5	2.5	-999	-999	-999	2.3	3.4	-999
Gerald Gentleman	41.1	-101.1	2.2	1	0.0	2.9	3.6	3.5	4.1	3.9	3.8	4.1	2.5	2.4	-999	-999
Harrington	35.3	-101.7	1.9	2	0.4	2.5	2.3	2.4	2.3	2.4	2.8	2.6	2.0	-999	-999	1.1
Independence	39.2	-111.0	2.5	5	0.5	5.1	4.3	3.9	2.9	2.4	2.4	2.4	2.1	2	2	3.0
Intermountain	35.7	-91.4	2.2	2	0.6	8.8	8.9	8.2	8.6	9.6	8.0	7.4	7.6	8	7	3.7
Miller Steam	39.5	-112.6	2.3	2	0.3	7.8	7.7	6.4	5.8	7.3	6.1	5.9	5.0	6	-999	4.8
Jeffrey Energy	33.6	-87.1	2.0	5	0.5	3.8	5.0	6.2	5.1	2.9	-999	-999	-999	-999	3	1.9
Jim Bridger	39.3	-96.1	-999	0	0.0	6.5	4.9	4.3	3.6	3.5	2.4	2.6	2.8	-999	2	-999
Joppa Steam	41.7	-108.8	2.0	5	0.6	6.2	5.9	4.9	4.3	4.7	3.9	3.7	-999	2	2	2.9
Laramie River	42.1	-104.9	1.9	2	0.1	9.6	9.6	8.5	6.6	6.5	-999	9.7	7.2	3	-999	-999
Martin Lake	32.3	-94.6	2.3	4	0.5	5.5	5.2	4.7	4.8	4.8	4.1	3.7	4.3	4	3	2.8
Monticello	33.1	-95.0	3.2	4	0.8	3.4	3.4	2.6	2.2	1.9	2.1	2.0	1.7	2	2	1.8
Navajo	36.9	-111.4	2.3	1	0.0	10.2	9.9	10.0	8.7	8.1	5.5	5.1	4.3	5	5	5.5
Powerton	40.5	-89.7	2.4	6	0.8	6.1	6.3	5.8	5.0	3.4	2.4	1.9	2.3	-999	-999	2.1
Rockport	37.9	-87.0	2.4	3	1.7	6.9	7.1	6.2	6.4	5.9	5.9	6.5	6.0	6	3	3.5
White Bluff	34.4	-92.1	4.3	4	0.6	4.5	4.0	3.9	2.9	3.7	3.4	3.4	2.4	2	2	2.8

[a]Num: the number of fits for wind direction sectors with a good fit performance; SD: the standard deviation of fits for wind direction sectors with a good fit performance. The fit results without a good fit performance (see criteria in Section 2.1) are recorded as -999.

Table S1. **Summary of power plants investigated in this study. The name for the 8 of the 21 plants with valid $E_{NO_x}^{Sat}$ are in bold.**

Name	Fit range	Integration interval	Fit error		SD of lifetime	Wind	NO_2 VCD	NO_x/NO_2	Wind dependency[a]	NO_x/CO_2	NO_x removal efficiency	Overall	Geometric Standard Deviation[b]
			Lifetime	Total NO_2 mass									
Four Corners & San Juan	10%	20%	10%	8%	20%	30%	30%	20%	10%	15%	N/A	60%	1.31
Independence			12%	16%							N/A	62%	1.25
Intermountain			15%	7%							N/A	61%	1.19
Martin Lake			20%	12%							N/A	63%	1.07
Monticello			13%	16%							20%	65%	1.19
Navajo			0%	8%							N/A	59%	1.18
Rockport			21%	20%							N/A	65%	1.12
White Bluff			15%	15%							N/A	62%	1.21

[a]Uncertainty arising from the effects of a possible systematic change of NO_2 tropospheric VCDs from calm to windy conditions.

[b]The geometric standard deviation (GSD) of the difference between $E_{CO_2}^{CEMS}$ and $E_{CO_2}^{Sat}$ from 2006* to 2016* for individual power plants.

Table S2. **Summary of uncertainties by source for power plants investigated in this study.**