Quantifying Point Source NO_x Emissions from TEMPO

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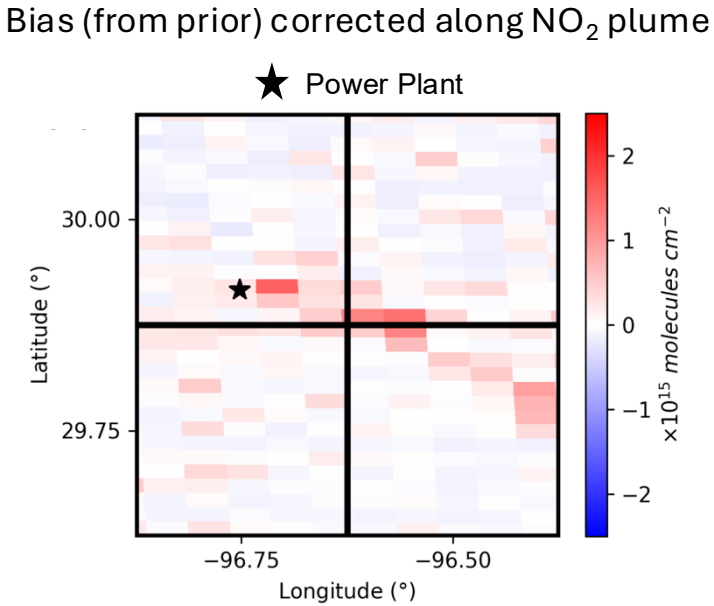
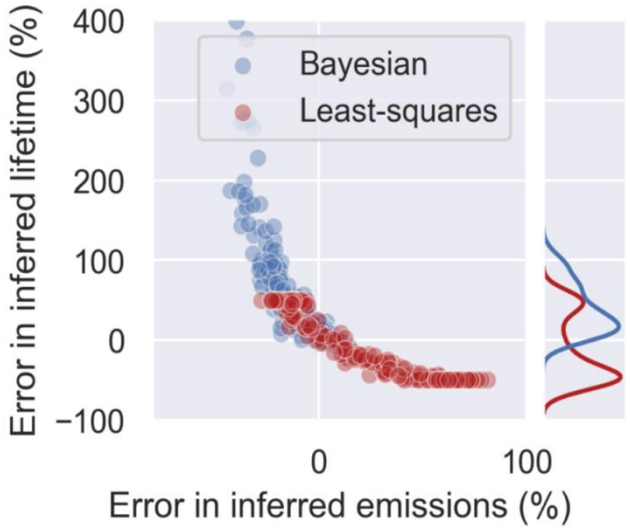
NO_x emitting power plants are validation tools for TEMPO

- Evaluate performance in a science application: deriving emissions
- Ground truth: *in situ* measurements of emissions
  - Continuous emissions monitoring systems (CEMS)
- Error sources in satellite-derived emissions:
  - **Retrieval**: noise, *a priori* information at lower resolution (Beaudry and Cohen, 2026; top)
  - **Derivation**: errors in meteorology and other derived parameters, especially NO_x lifetime (Mols et al., 2026; bottom)

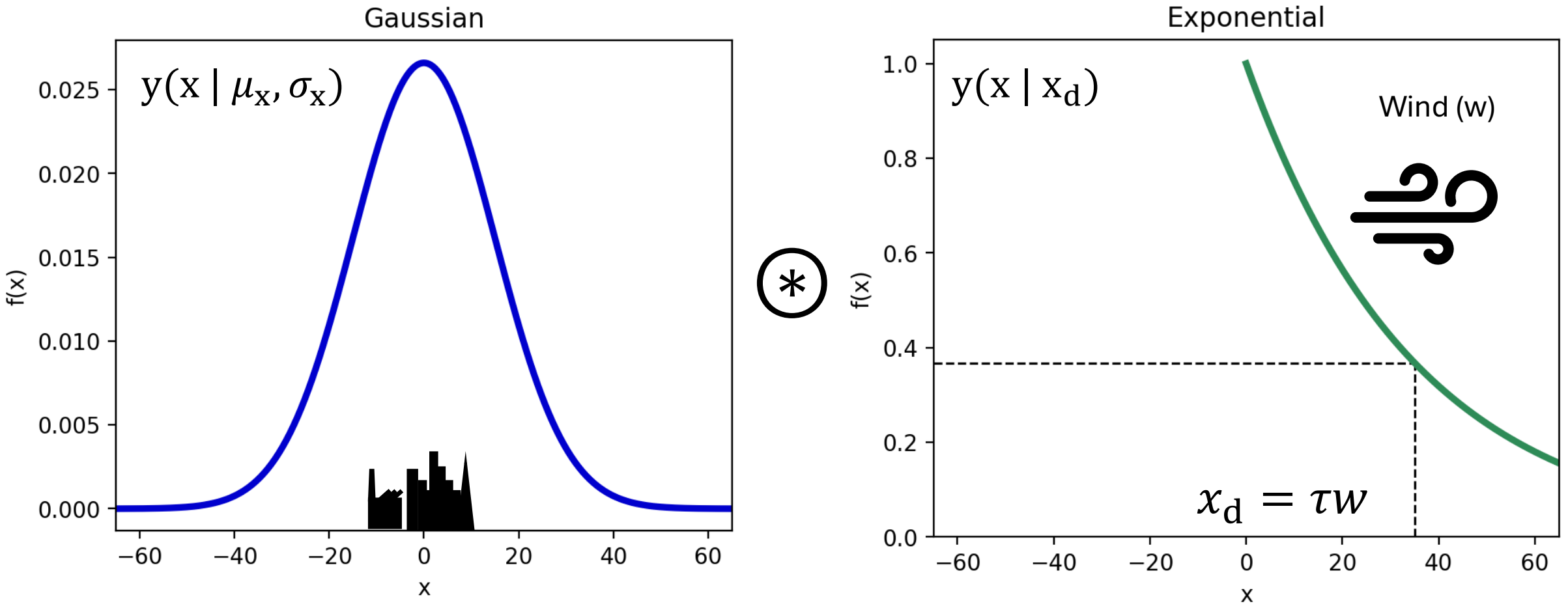




Research Objectives

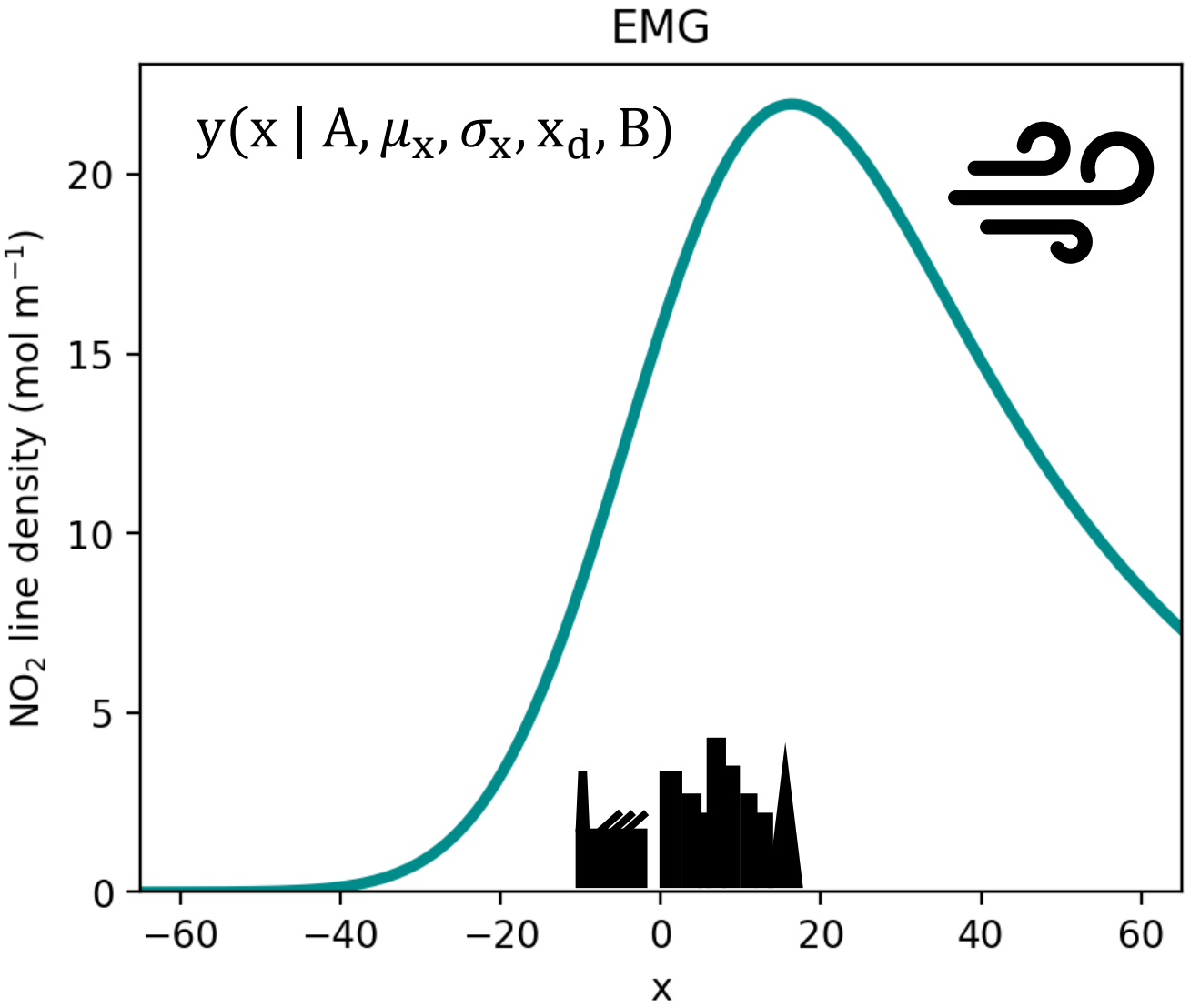
- What is an appropriate model for point source NO_x plumes?
- How accurate are TEMPO-derived emissions compared to ground truth values from CEMS?
- What is the lowest NO_x emission rate that can reliably be quantified with TEMPO?

Exponentially Modified Gaussian (EMG) is commonly used to derive emissions



e.g. Beirle et al. (2011), Valin et al. (2013), Laughner and Cohen (2019), Jin et al. (2021), Pommier (2022), Beirle and Wagner (2024)

EMG is not the best choice for point sources

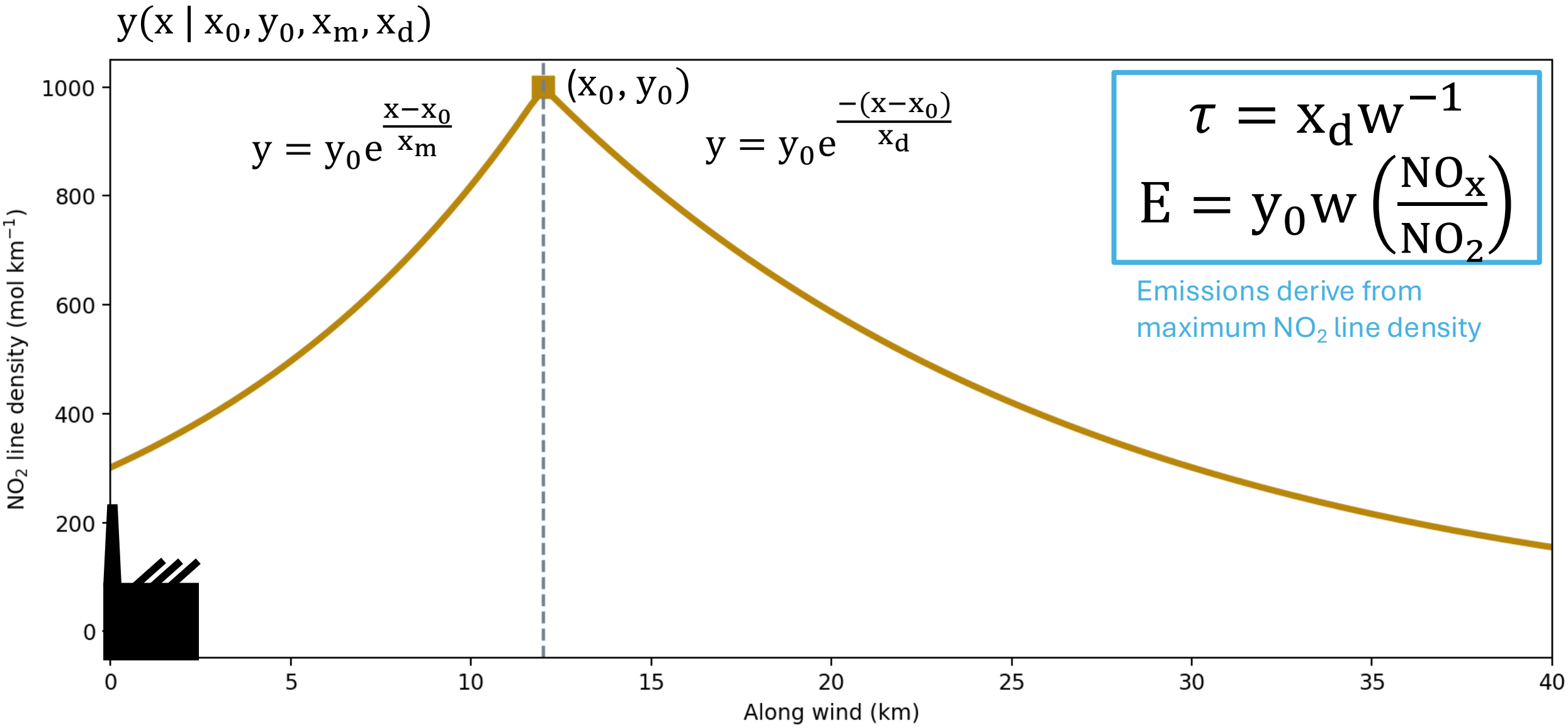


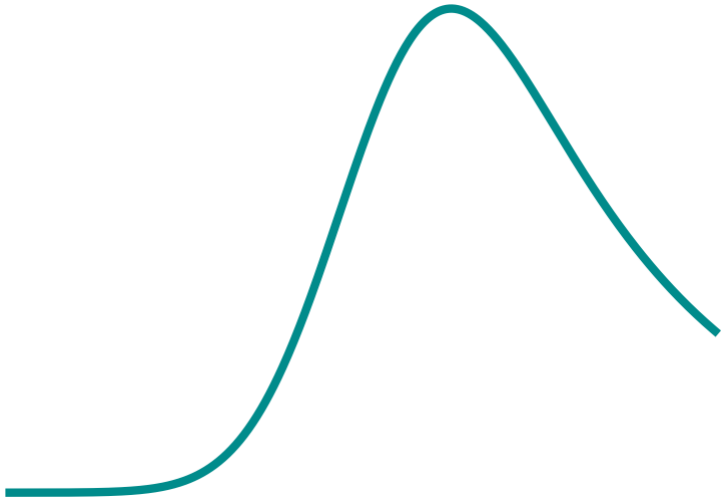
- Point source resembles delta function more than Gaussian.
- Issues distinguishing 5 parameters, such as spread (σ_x) and e-folding (x_d).

$$\tau = x_d w^{-1}$$
$$E = A\tau^{-1}\left(\frac{NO_x}{NO_2}\right)$$

Emissions derive from plume mass (A) and lifetime (τ)

Rise/Decay (RD) model for point source emitters

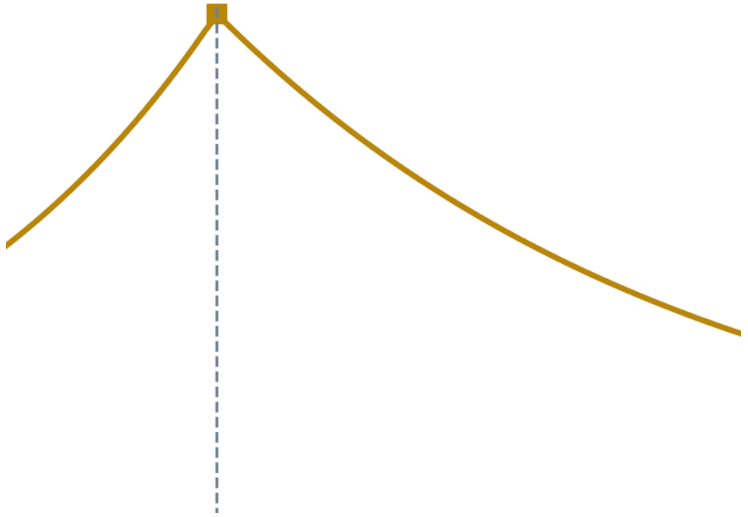




EMG

$$y(x \mid A, \mu_x, \sigma_x, x_d, B)$$

- Convolution
- Treats source as Gaussian
- Emission calculated from mass (A), e-folding (x_d), and wind speed (w)



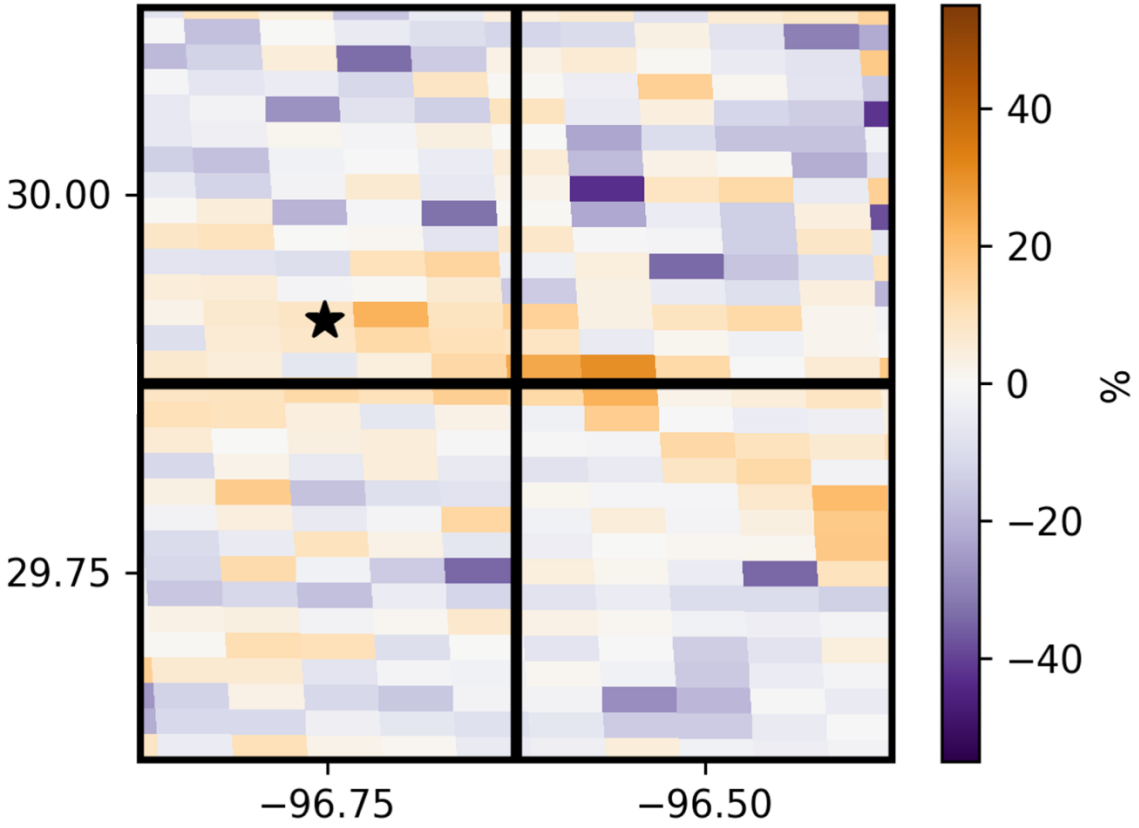
Rise/Decay

$$y(x \mid x_0, y_0, x_m, x_d)$$

- Piecewise
- Treats source as a delta function
- Emission calculated from maximum density (y_0) and wind speed (w)

Signal-Derived Retrieval (SDR) applied before analysis

Relative Difference
(SDR vs. V03)



★ Sam Seymour Power Plant

Corrects bias introduced by using 25 km GEOS-CF prior, which:

- ↑ Maximum line density (y_0)
- ↑ Plume mass (A)
- ↓ Lifetime (τ)

$$\uparrow E_{RD} = y_0 w \left(\frac{NO_x}{NO_2}\right)$$

$$\uparrow E_{EMG} = \frac{A}{\tau}\left(\frac{NO_x}{NO_2}\right)$$

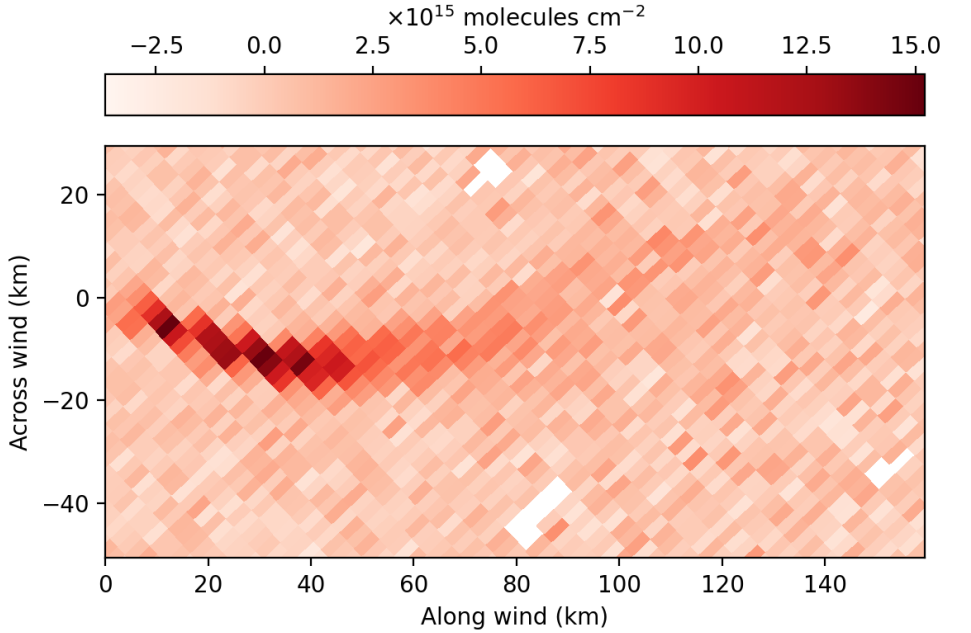
Beaudry and Cohen, 2026,
JGR Atmospheres

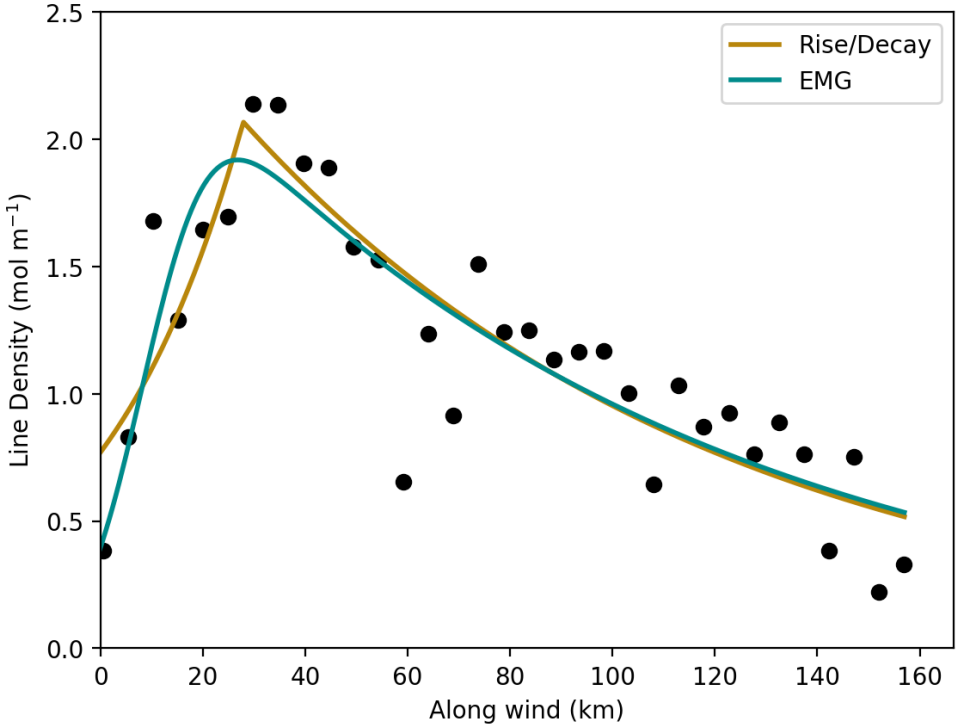
Example fits at strong emitter

- Maximum line density observed 30 km downwind from source.
- Both methods underestimate CEMS for very high emission source.

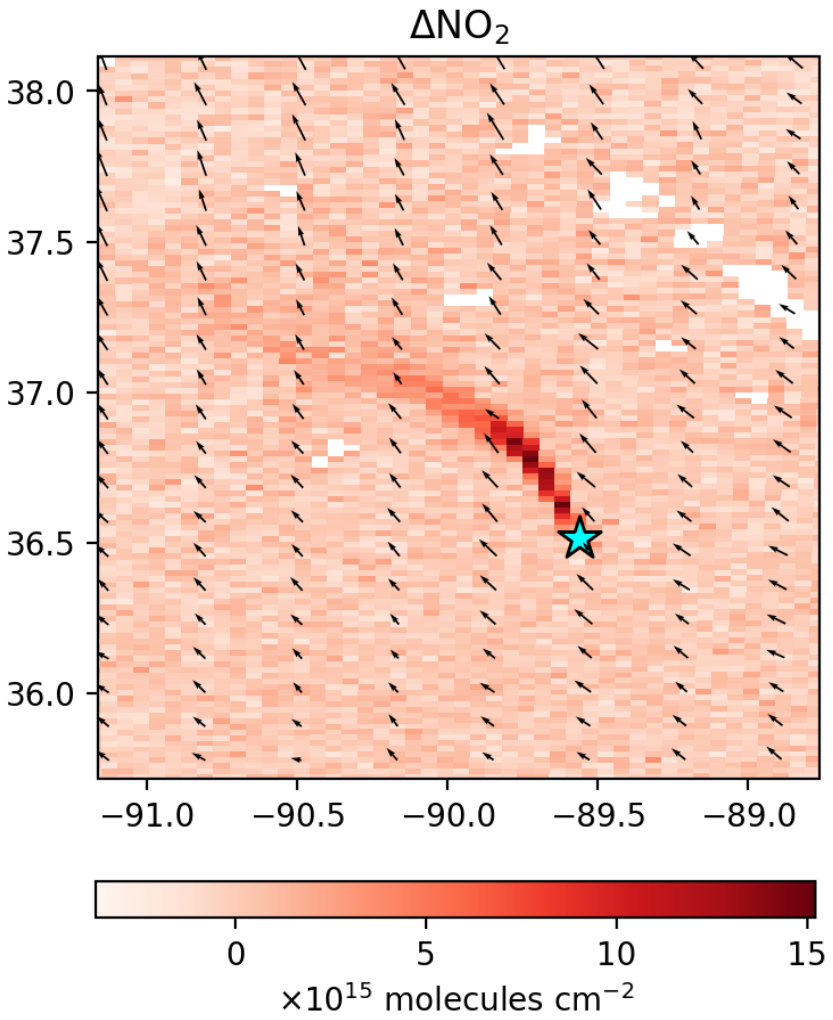
[kg/hr]	TEMPO Derived	CEMS
Rise/Decay	1,400	3,542
EMG	1,700	

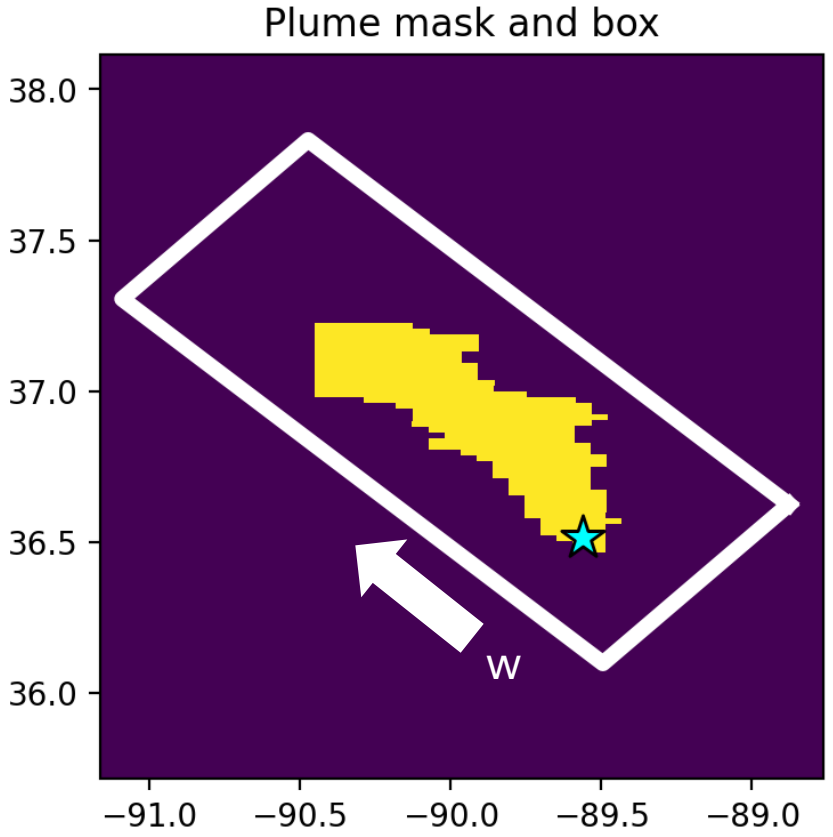
New Madrid Power Plant
2025-11-06 (13:52 LST)
Wind: 4.1 m/s





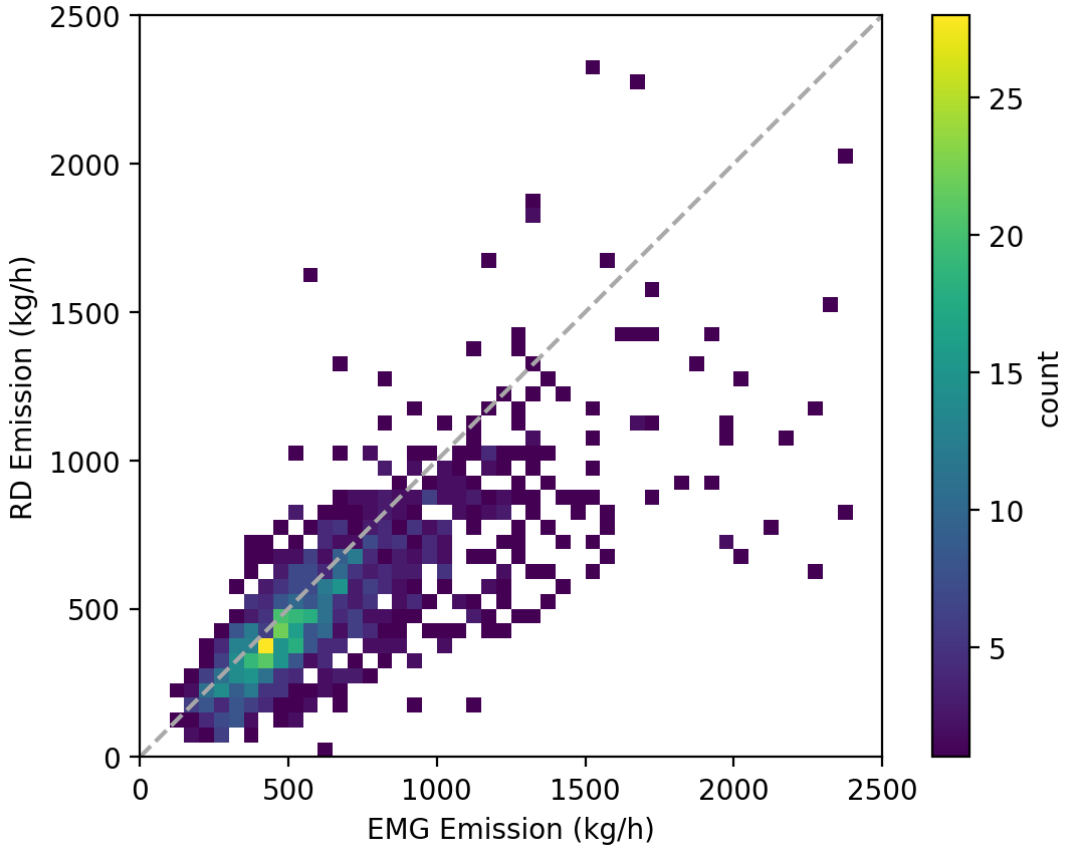
Plumes detected and fit for 6 months of V04 TEMPO-SDR data

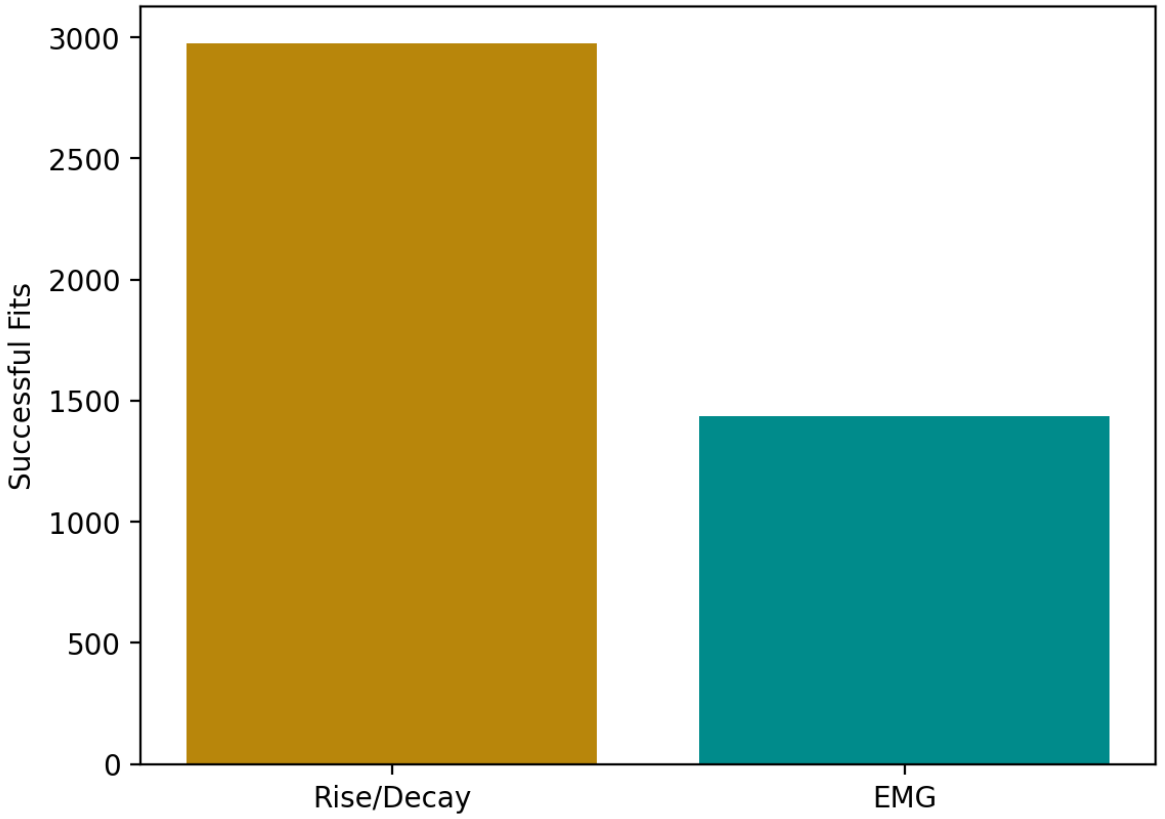




- Over 100 isolated/rural power plants with reported CEMS emissions
- ~ 5% of observations flagged as plumes
- 2 m/s minimum wind speed

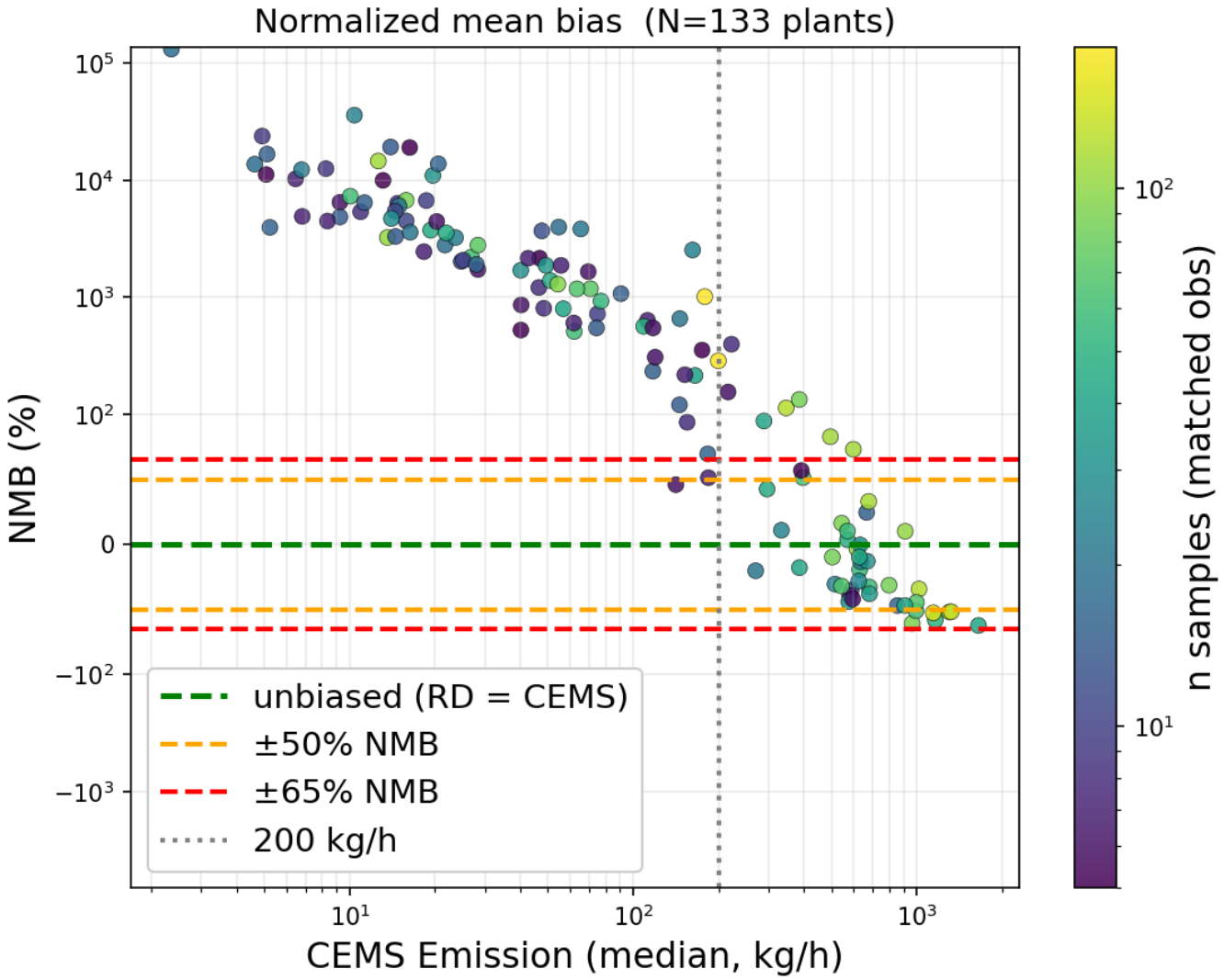
Twice as many rise/decay fits as EMG fits





- Rise/decay and EMG emissions are comparable at top 70 isolated plants.
- Rise/decay, with fewer parameters to optimize, has more successful fits.
- EMG frequently fails to simultaneously derive realistic emissions and lifetimes.

Bias against CEMS varies with emission rate

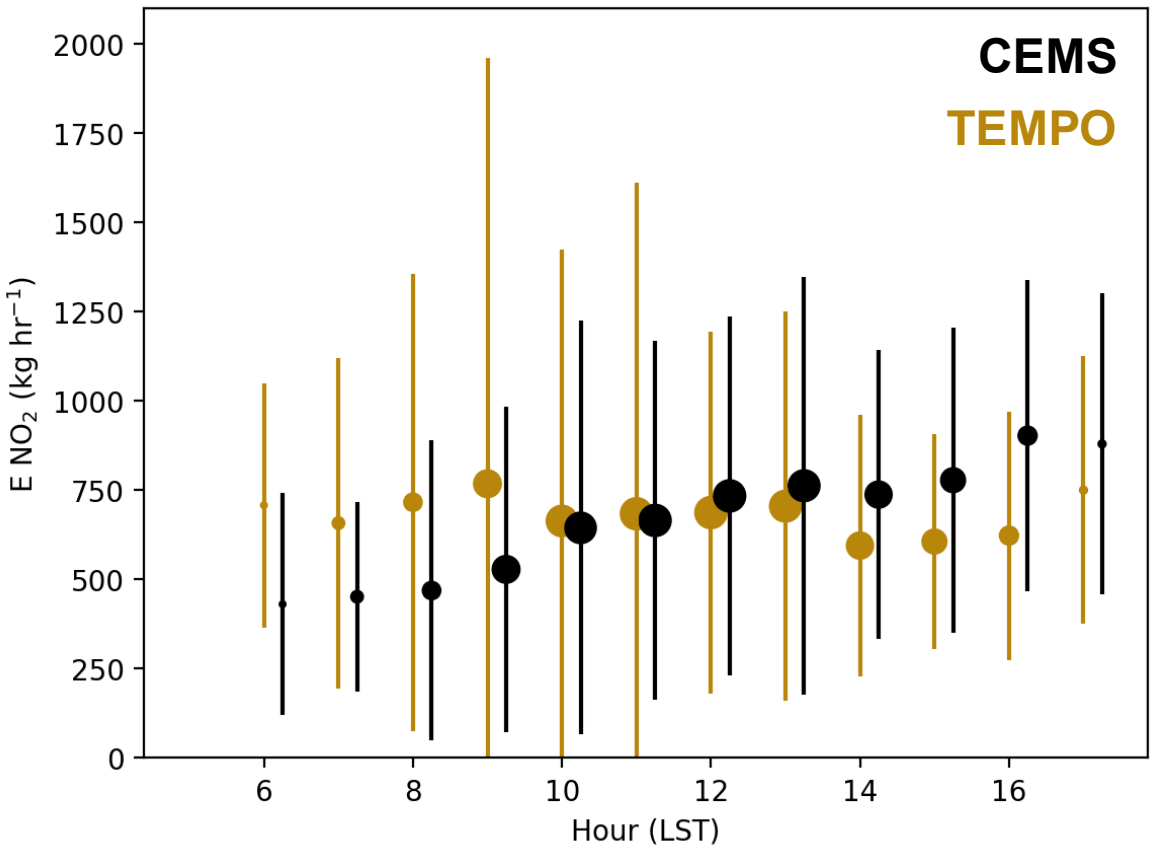


- Lower emitters are overestimated, higher emitters are underestimated
- The highest emitters give an incomplete picture
- Emission must be at least 200 kg/hr to reliably detect and quantify

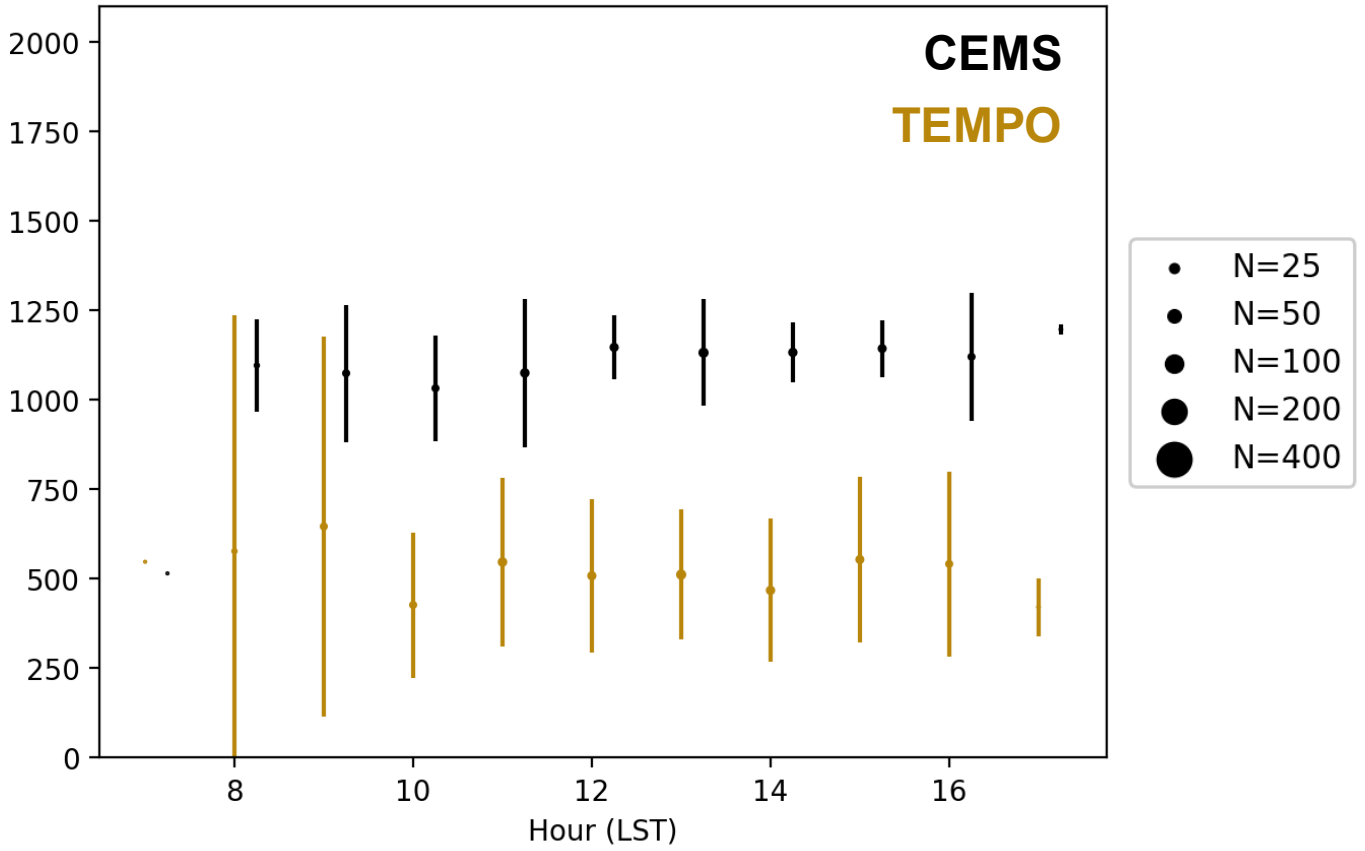
$$\mathrm{NMB} = \frac{\Sigma(\mathrm{RD} - \mathrm{CEMS})}{\Sigma(\mathrm{CEMS})} \times 100\%$$

Relatively small diurnal variation in TEMPO and CEMS emissions

71 plants (N = 2977)



Example plant: Gerald Gentleman, NE (N = 151)



Points: mean

Error bars: ± 1 standard deviation

Takeaways

- What is an appropriate model for point source NO_x plumes?
  - Rise/decay is a point source specific model which produced a larger collection of emissions.
- How accurate are TEMPO-derived emissions compared to ground truth values from CEMS?
  - TEMPO emissions overestimated at lower emitters, underestimated at higher emitters.
  - No apparent bias vs. time of day (using version 4).
- What is the lowest NO_x emission rate that can reliably be quantified with TEMPO?
  - Emissions are more reliably estimated above 200 kg/hr.

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