A proposed top-down/bottom-up inventory of coal mine methane with remote sensing observations

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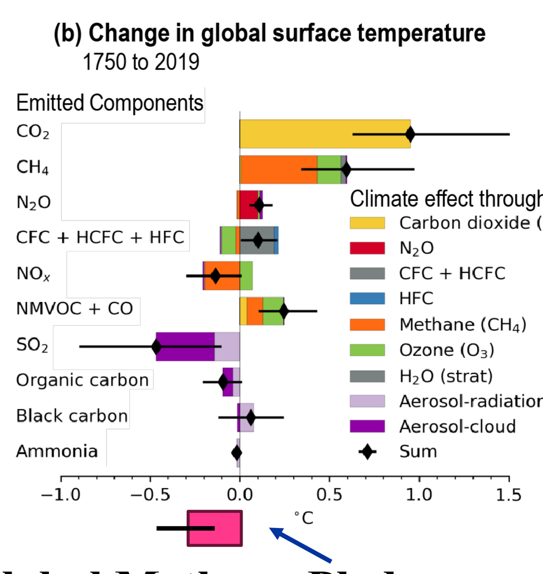
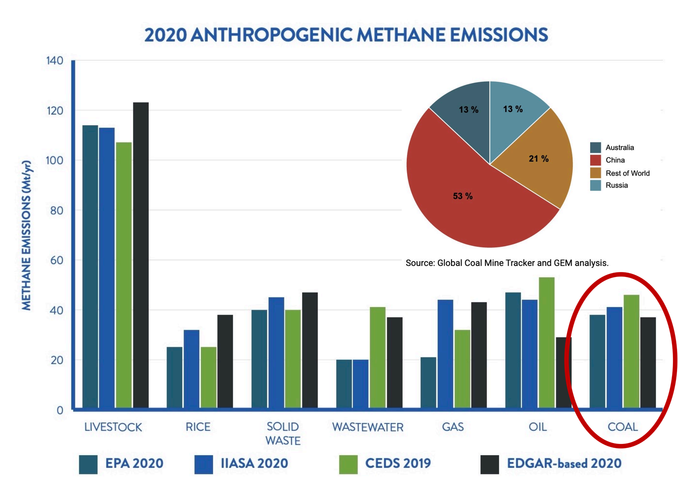
Mitigation of methane emissions is a powerful lever for short-term climate change action.



Global Methane Pledge
if emissions remain reduced through 2050
(Cael & Goodwin, 2023)



Methane emissions from coal mines are **as large as oil or gas**

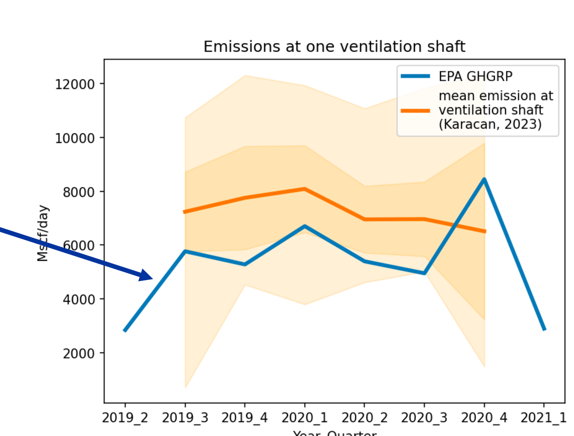
Most global inventories rely on emissions factors, leading to high uncertainty.

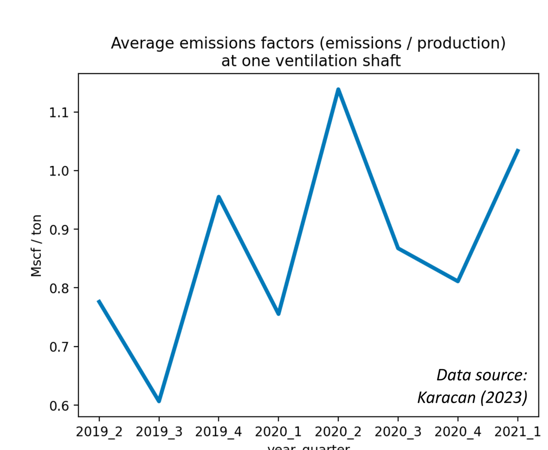
Global inventories of coal mine methane use emission factors to estimate methane emissions:

$$E = Emission\ Factor \times Production$$

- Emissions factors differ **between mines** (from 0-300+ m^3/ton) (Kholod et al., 2020).
- Emissions factors change **based on operational & geological factors** (~2x)

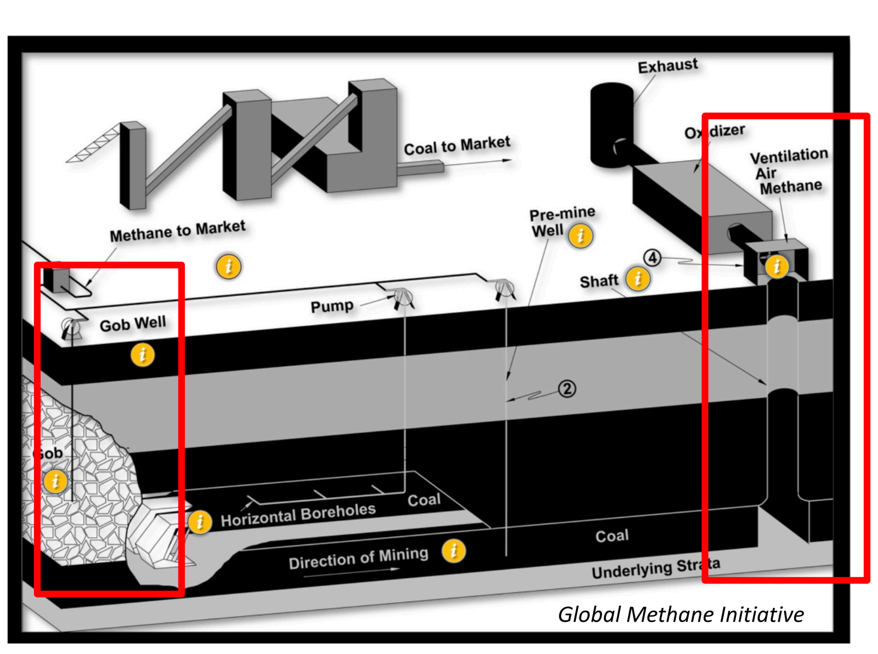
Data reported to EPA lower than the mean, but within uncertainty range





- The standard deviation of emissions over a quarter is only ~20%.

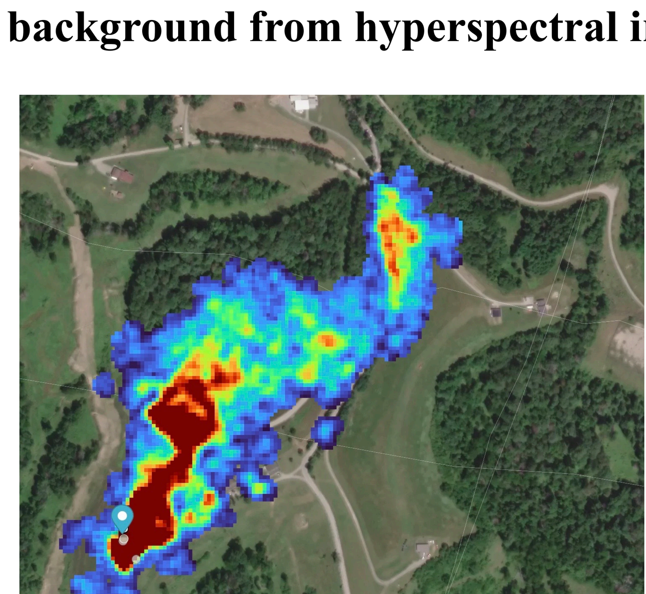
Methane is released through ventilation shafts and degasification wells.



- In the US:
  - 83% of methane from **degasification wells** is collected
  - Nearly all of the methane from **ventilation shafts** is released, and these account for over half of all coal mine methane emissions in the US.
  - Methane emissions are **measured and reported at least quarterly** at ventilation shafts & degasification wells

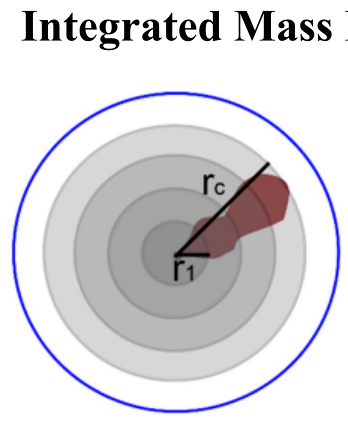
Emissions rates at point sources can be estimated with observations from aircraft and satellites.

1. Retrieve methane enhancement over background from hyperspectral image.



Methane plume over coal mine vent detected by Global Airborne Observatory (GAO).

2. Calculate methane emissions with Integrated Mass Enhancement (IME).



Sum mass enhancement over radius:

$$IME_{r_c} = k \sum_{i=0}^{n} \alpha(i) S(i)$$

mass enhancement

area

Calculate emissions rate:

$$Q = \frac{1}{\tau} \overline{IME} = \frac{U_{10}}{\bar{r}} \overline{IME}$$

lifetime of methane inside the radius w.r.t. ventilation

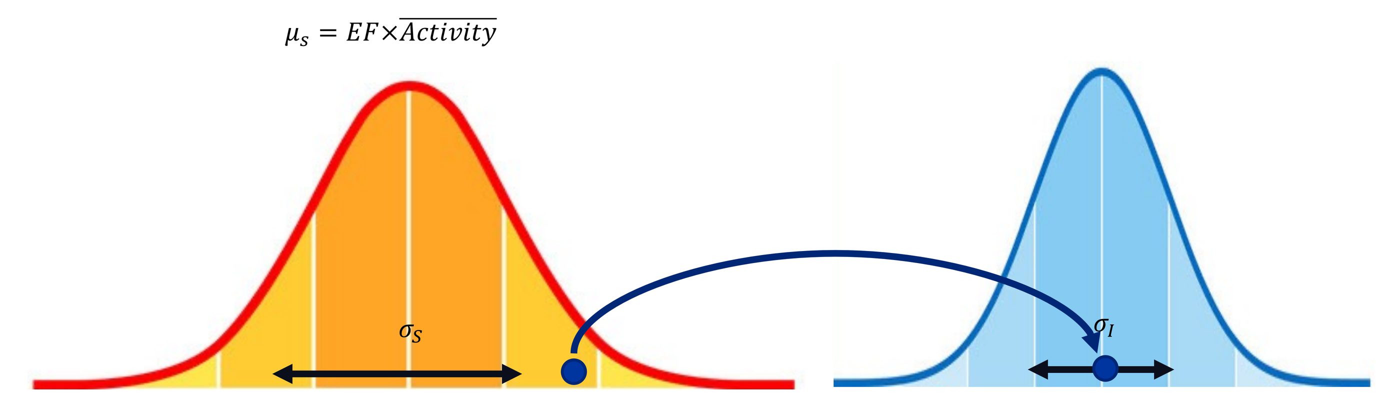
Duren et al., 2019

With repeated remote sensing observations, emissions from US underground mines can be estimated.

Mean emissions μ_S from a coal mine + variability σ_S

Measured emissions + measurement error σ_I

$\mu_S = EF \times \overline{Activity}$



assuming independent errors: $\sigma = \sqrt{\sigma_S^2 + \sigma_I^2}$

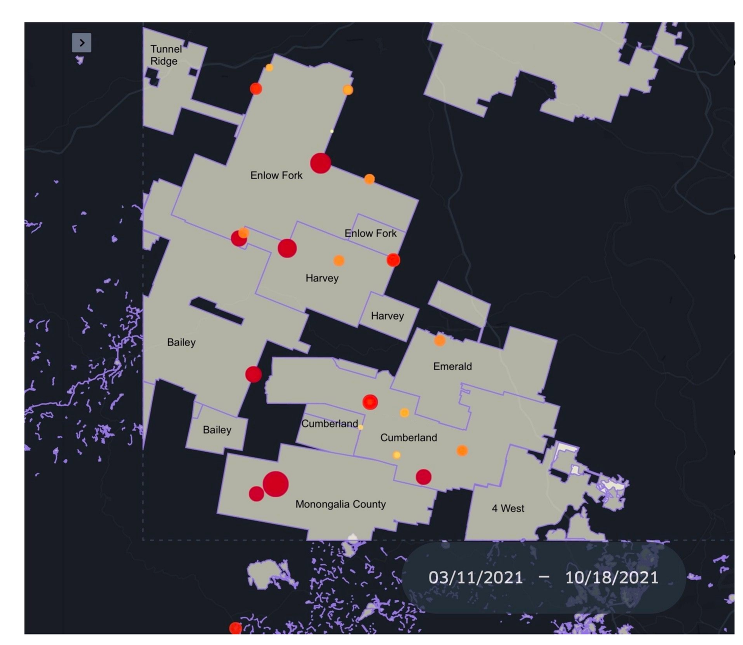
With repeated observations… $\sigma_{mean} = \frac{\sigma}{\sqrt{N}}$

$$Emissions\ Factor \times \overline{Production} = \overline{Emissions}$$

estimate emissions factor for each mine

From MSHA+EIA

We find evidence the US EPA inventory of underground coal mines may underestimate methane at some mines.



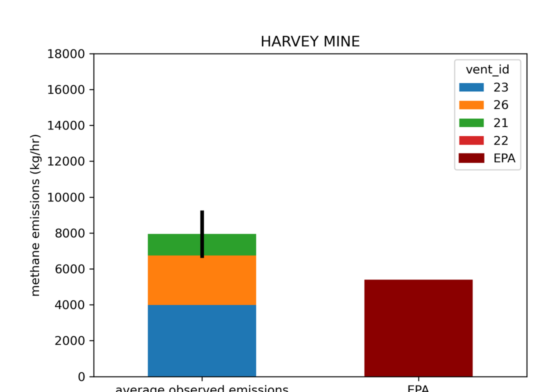
We can attribute plumes (colored dots) to specific mines

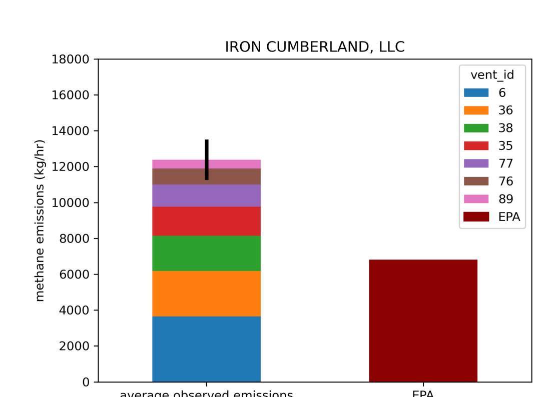
CarbonMapper flights
- 2021-2023, PA/WV, Alberta, Alabama, Chile, Wyoming

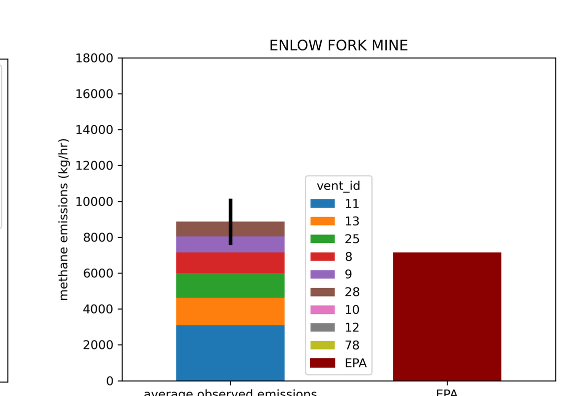
EPA GHGRP measurements
- Quarterly for shafts, weekly for gob gas wells – **through 2022**

State infrastructure maps
- Underground permit boundaries (PA)
- Surface permit boundaries (WV)

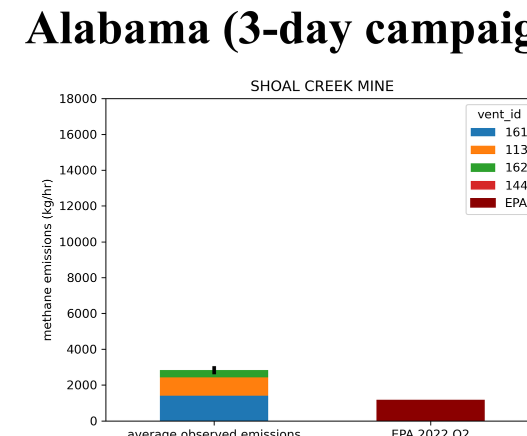
Pennsylvania (3-day campaign)

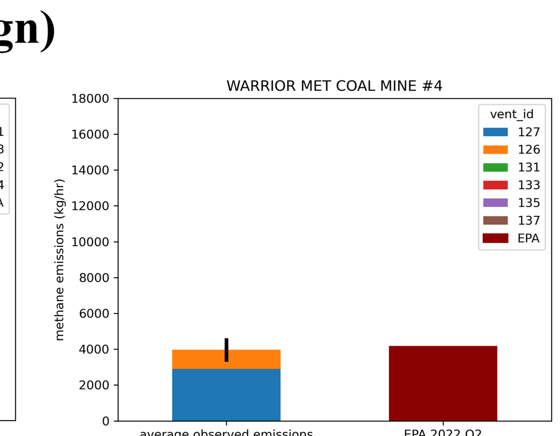


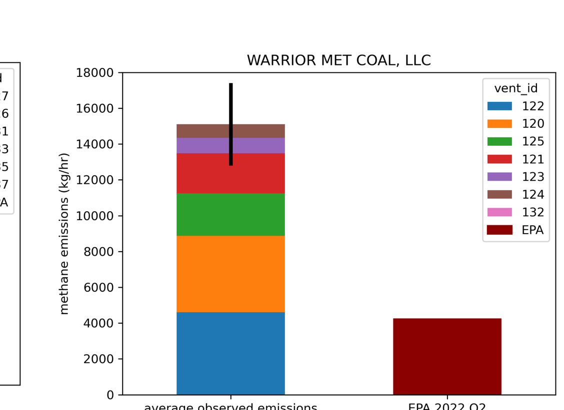




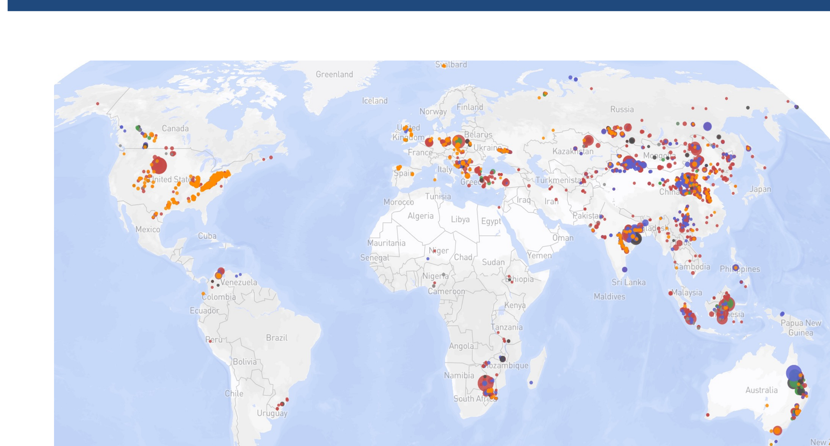
Alabama (3-day campaign)



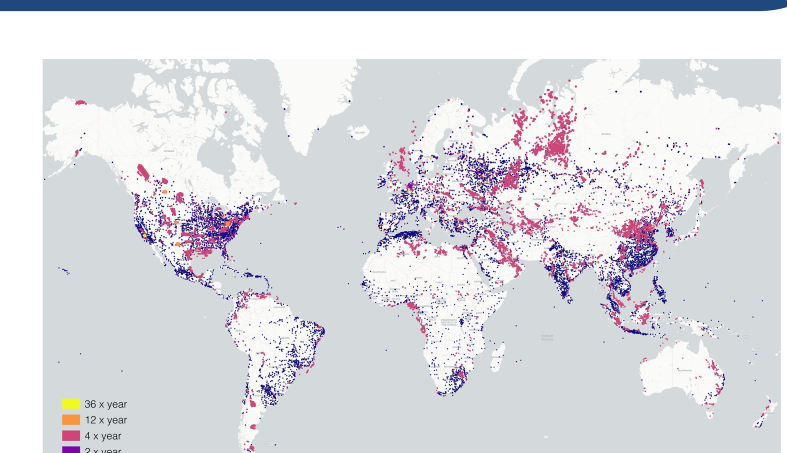




Future satellite capability may make it possible to measure coal mines globally.



Global coal plant tracker (Global Energy Monitor)



Notional CarbonMapper tasking deck (CarbonMapper, Inc)

Acknowledgements

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