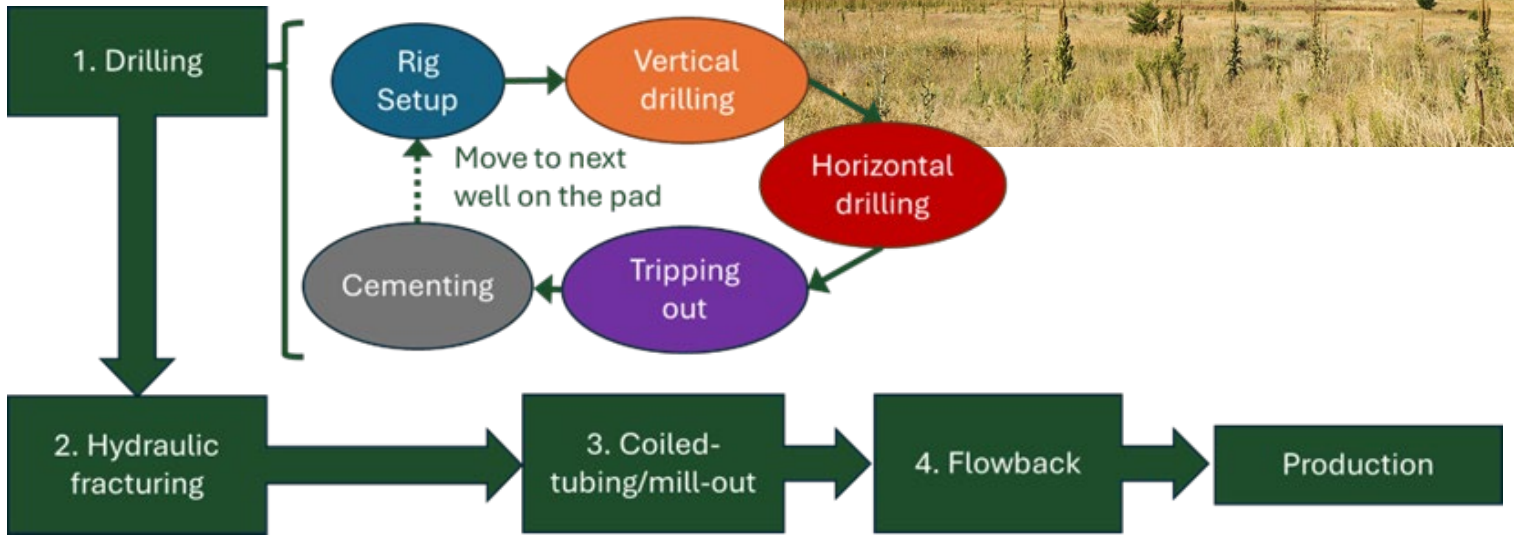
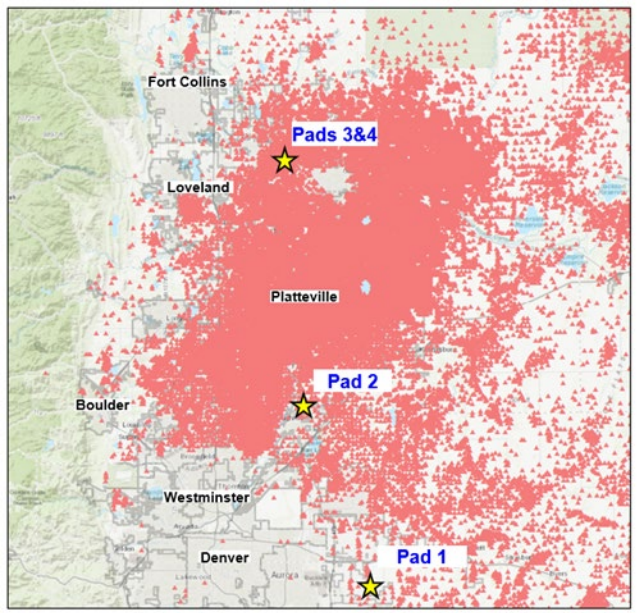
Modeling VOC concentration increases near oil and gas well drilling, completion, and production operations

Jeff Collett, D. Pan, W. Zhang, Y. Zhou, I-T. Ku, J. Pierce, D. Zimmerle, J. Duggan, and E. Rimelman



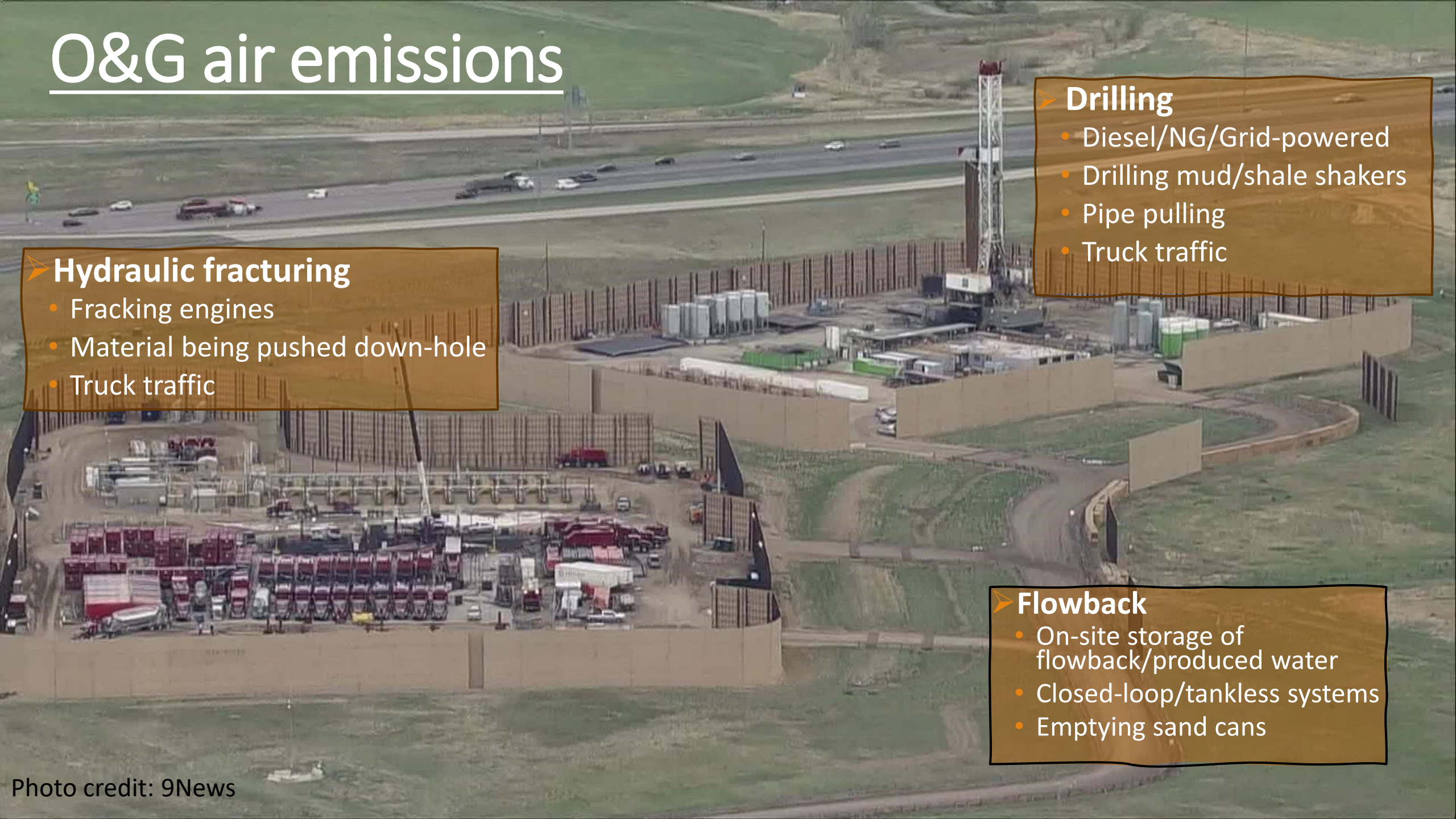
HEI energy
Colorado State University
colorado school of public health
UNIVERSITY OF COLORADO
COLORADO STATE UNIVERSITY
UNIVERSITY OF NORTHERN COLORADO
COLORADO
Department of Public Health & Environment

DJ Basin air monitoring approach



- 3 sites, 4 well pads, 3 O&G operators
- CDPHE CAMML
  - Hourly speciated VOCs, CH_4, NO_x, $PM_{2.5}$
- Weekly integrated VOC canisters
  - 51 speciated VOCs + CH_4
  - 2 near-pad locations plus background reference site
- Continuous PID monitors with event-triggered canister samples
  - 2 near-pad locations
- Mobile measurements
  - CH_4 and VOCs

O&G air emissions



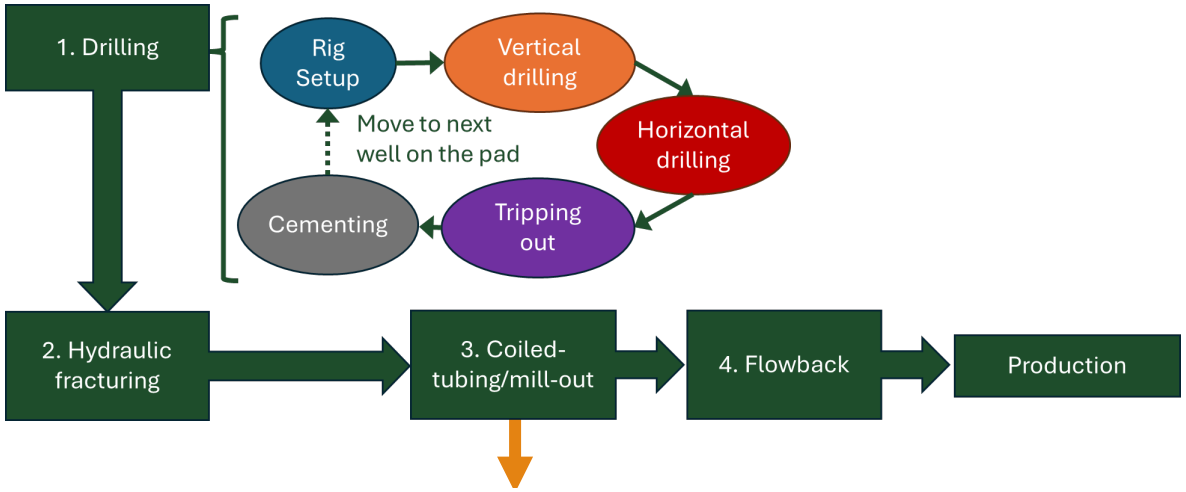
Drilling
- Diesel/NG/Grid-powered
- Drilling mud/shale shakers
- Pipe pulling
- Truck traffic

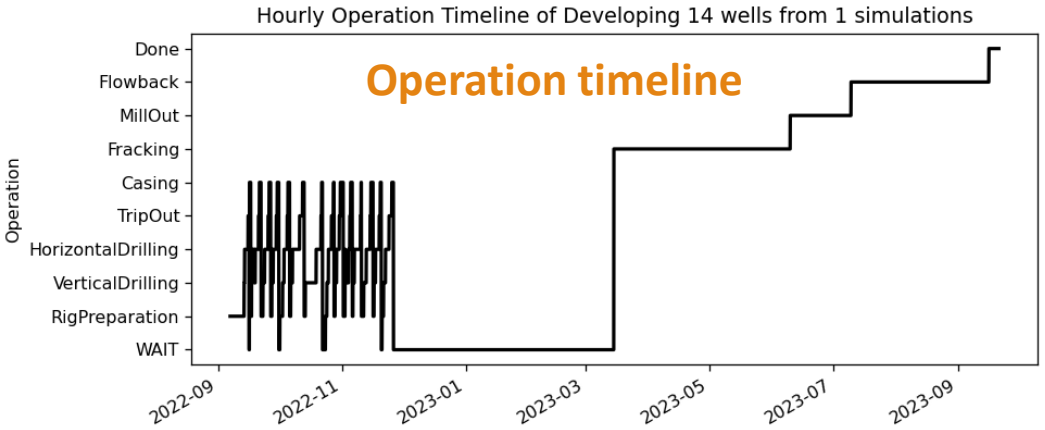
Hydraulic fracturing
- Fracking engines
- Material being pushed down-hole
- Truck traffic

Flowback
- On-site storage of flowback/produced water
- Closed-loop/tankless systems
- Emptying sand cans

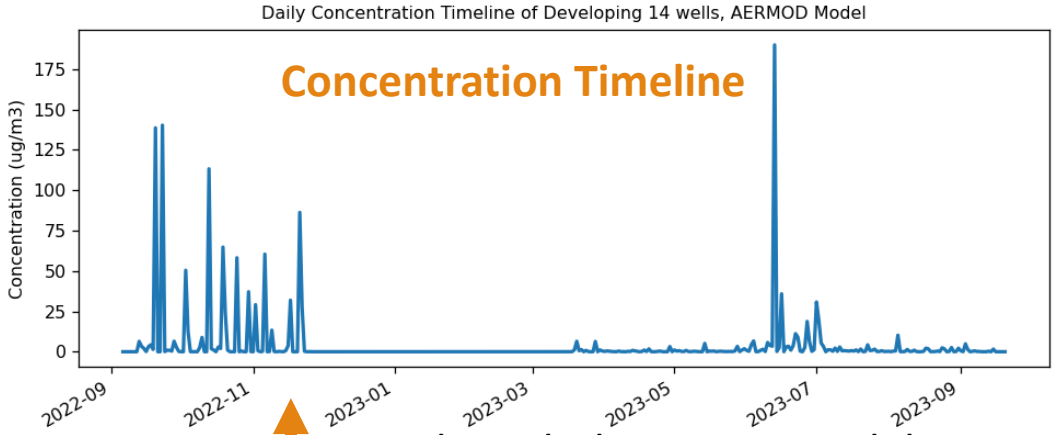
Photo credit: 9News

TRACER pre-production model

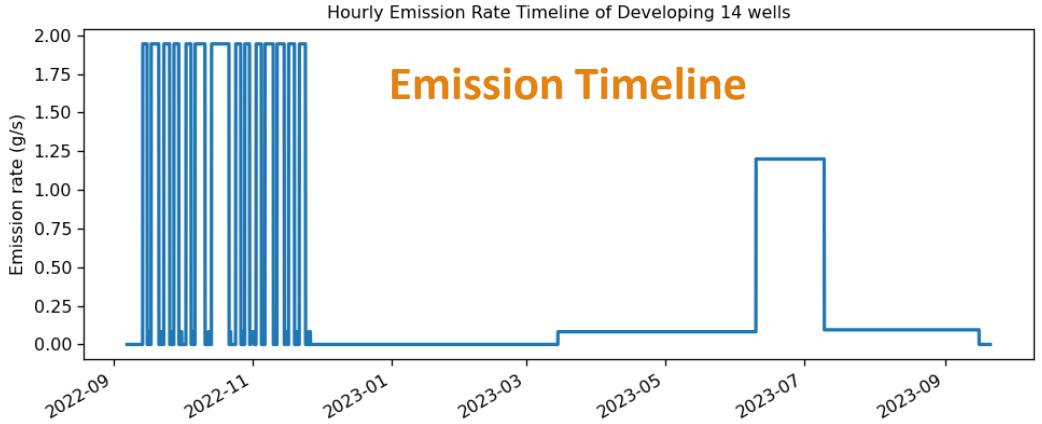




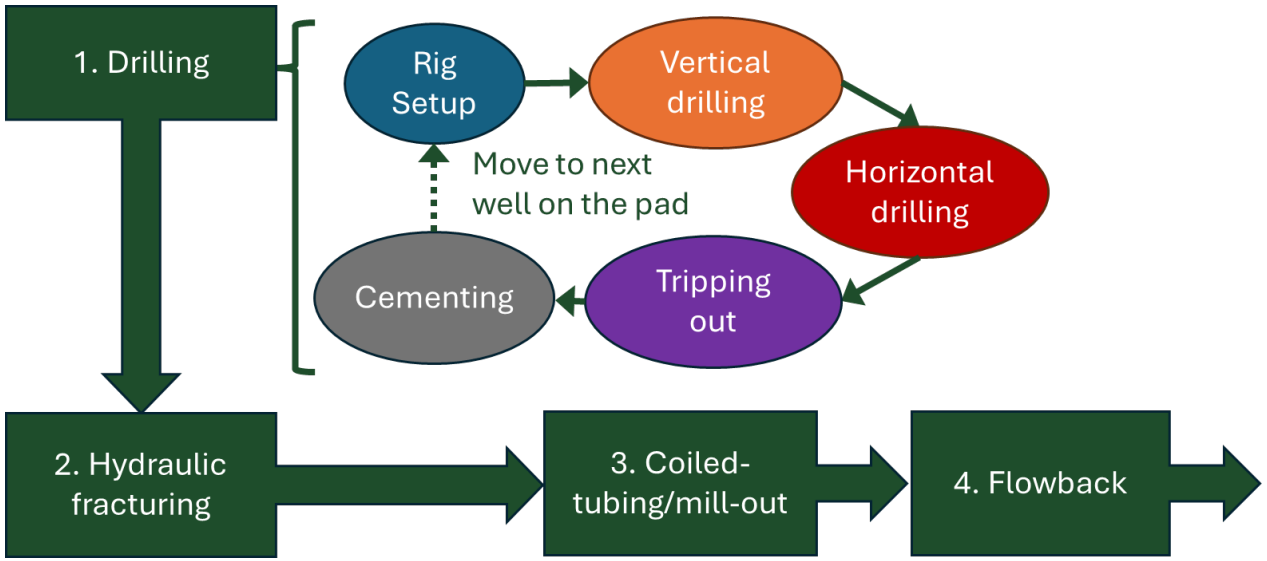
Select Emission Factor



Couple with dispersion model



TRACER pre-production model emissions



EMISSION DATA SOURCES

EPA O&G Emission Tool

Hecobian et al. (2019)

Gaps & Limitations

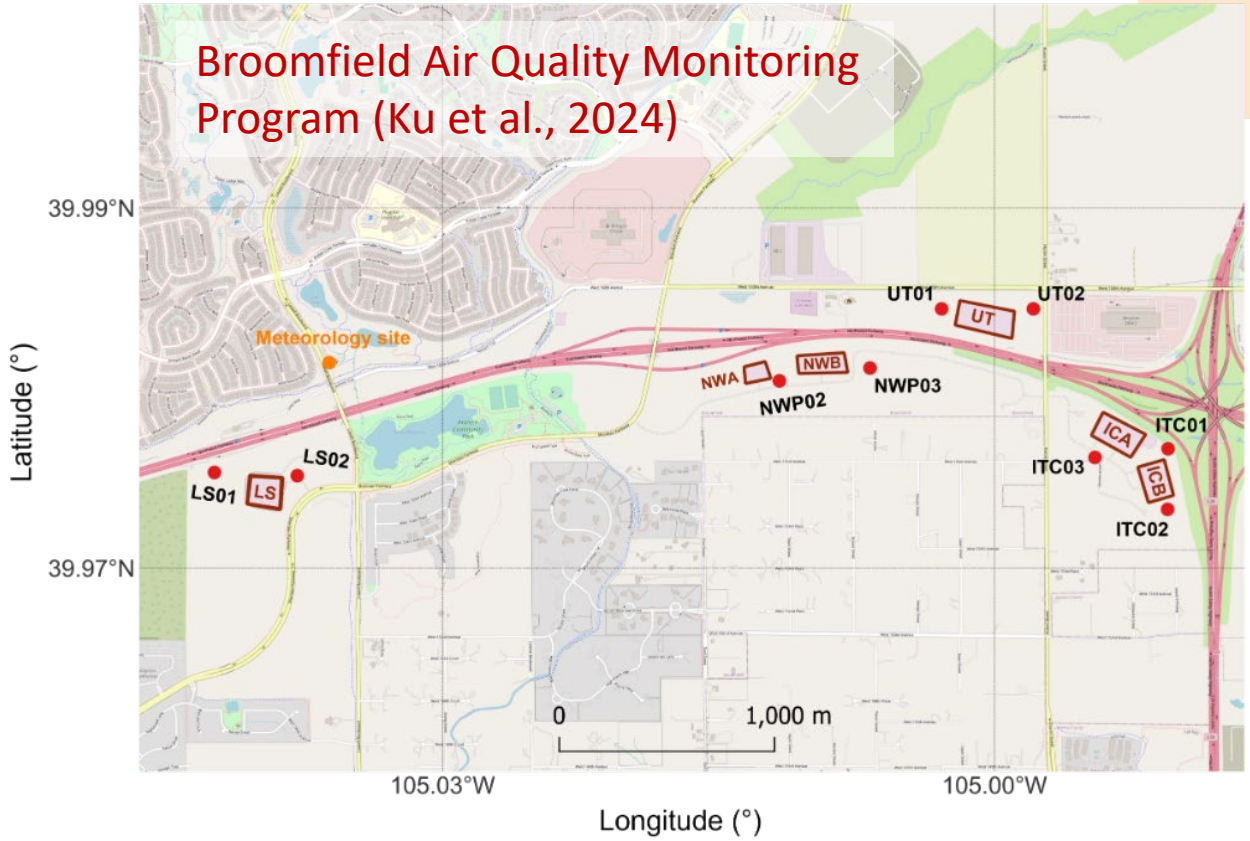
- Missing some operations (e.g., coil tubing/mill-out)
- Evolving operational practices (e.g., flowback fluids handling)
- Sometimes lack full VOC speciation

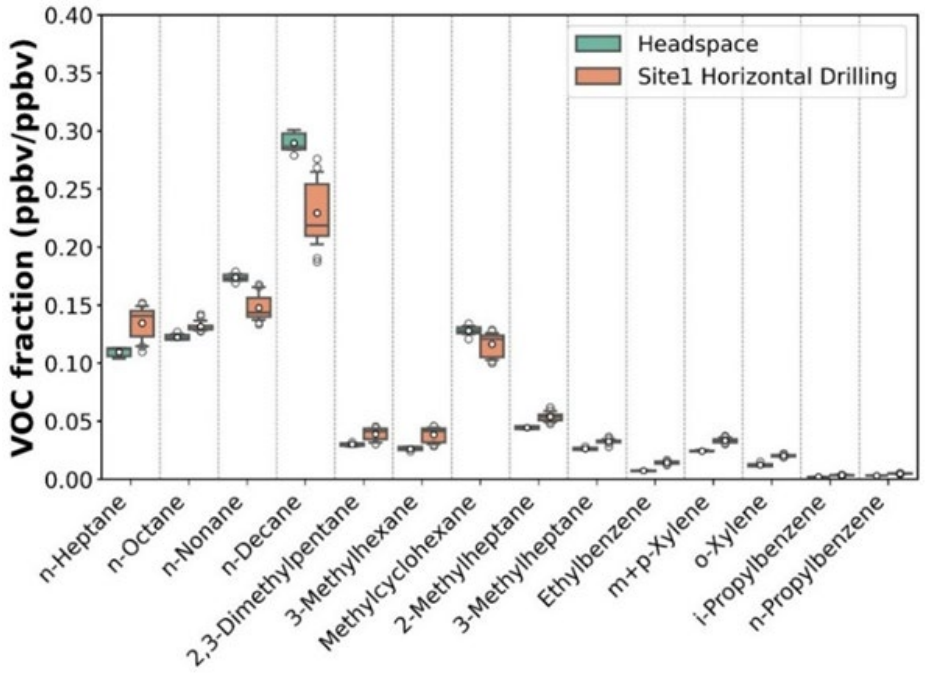
Hecobian et al. (2019) Air toxics and other VOC emissions from UOGD, *Env. Sci. Technol. Lett.*, doi: 10.1021/acs.estlett.9b00591.

Constraining UOGD VOC emission rates

- Use multiple linear regression to constrain Broomfield VOC emission rates using AERMOD and ambient VOC concentrations

$$\begin{pmatrix} C_1 \\ \vdots \\ C_n \end{pmatrix} = C_{bg} + \begin{pmatrix} M_{1,1} & \cdots & M_{1,m} \\ \vdots & \ddots & \vdots \\ M_{n,1} & \cdots & M_{n,m} \end{pmatrix} \cdot \begin{pmatrix} e_1 \\ \vdots \\ e_m \end{pmatrix}$$





Ku et al. (2024) Air quality impacts from the development of unconventional oil and gas well pads: Air toxics and other volatile organic compounds. *Atmos. Environ.*, 120187. https://doi.org/10.1016/j.atmosenv.2023.120187.

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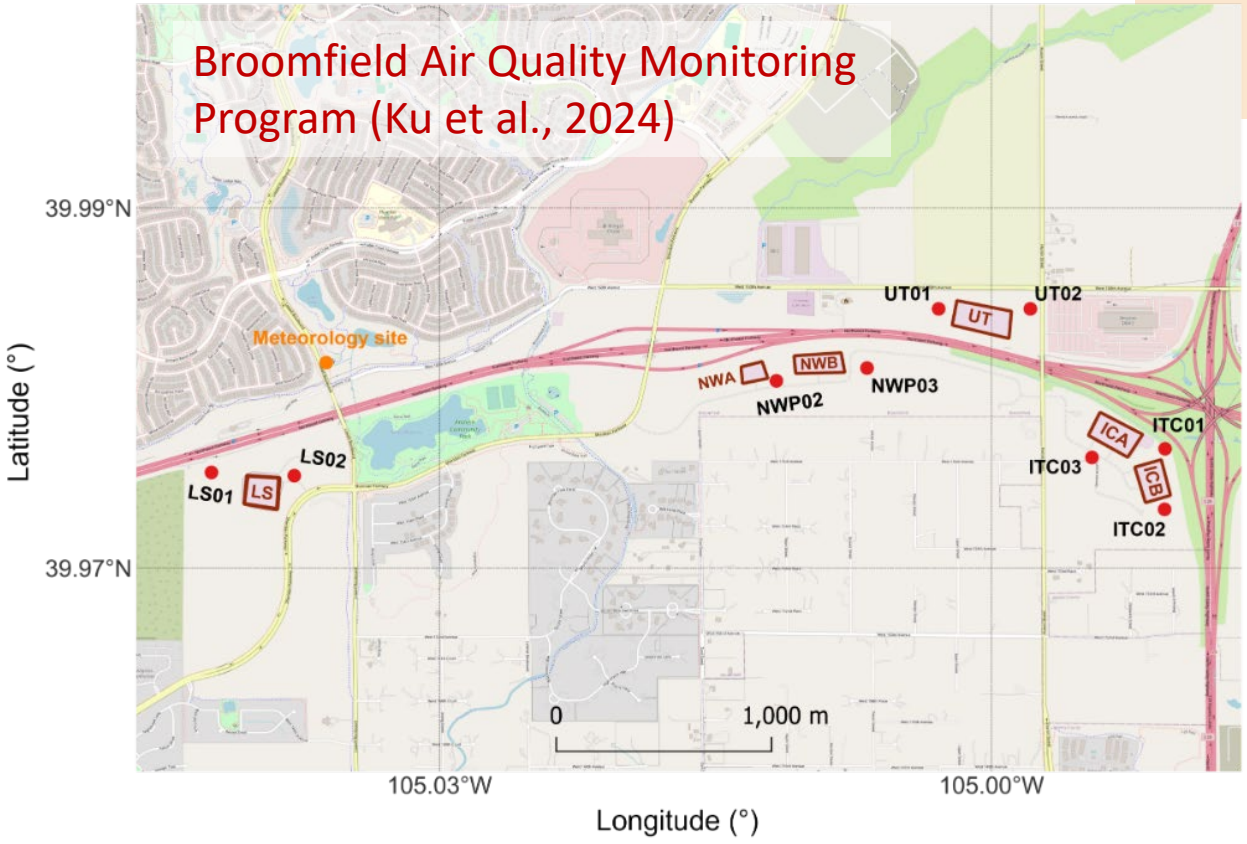

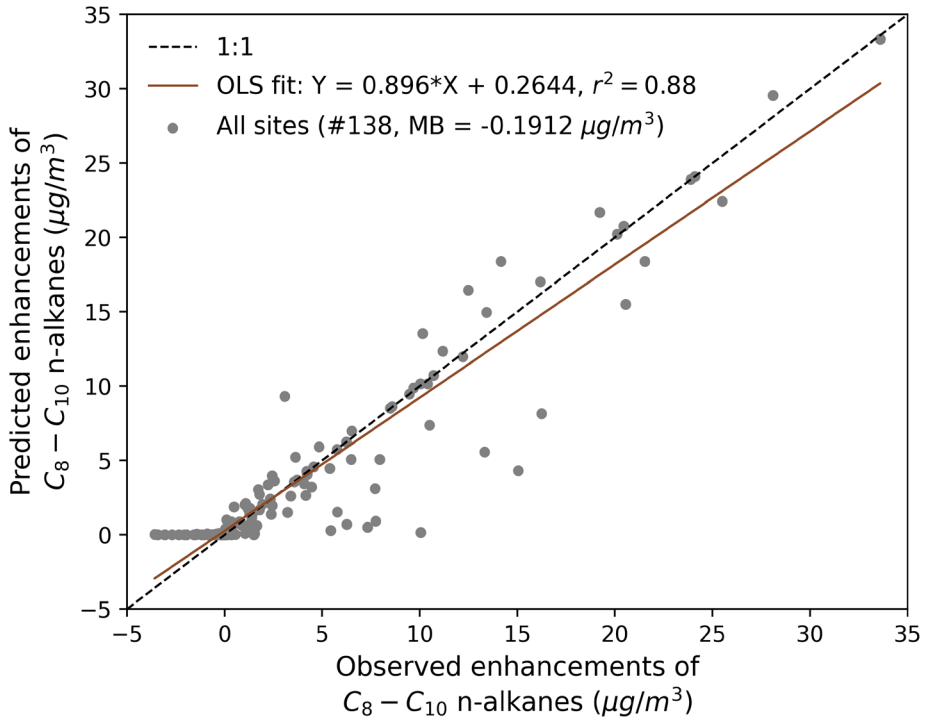

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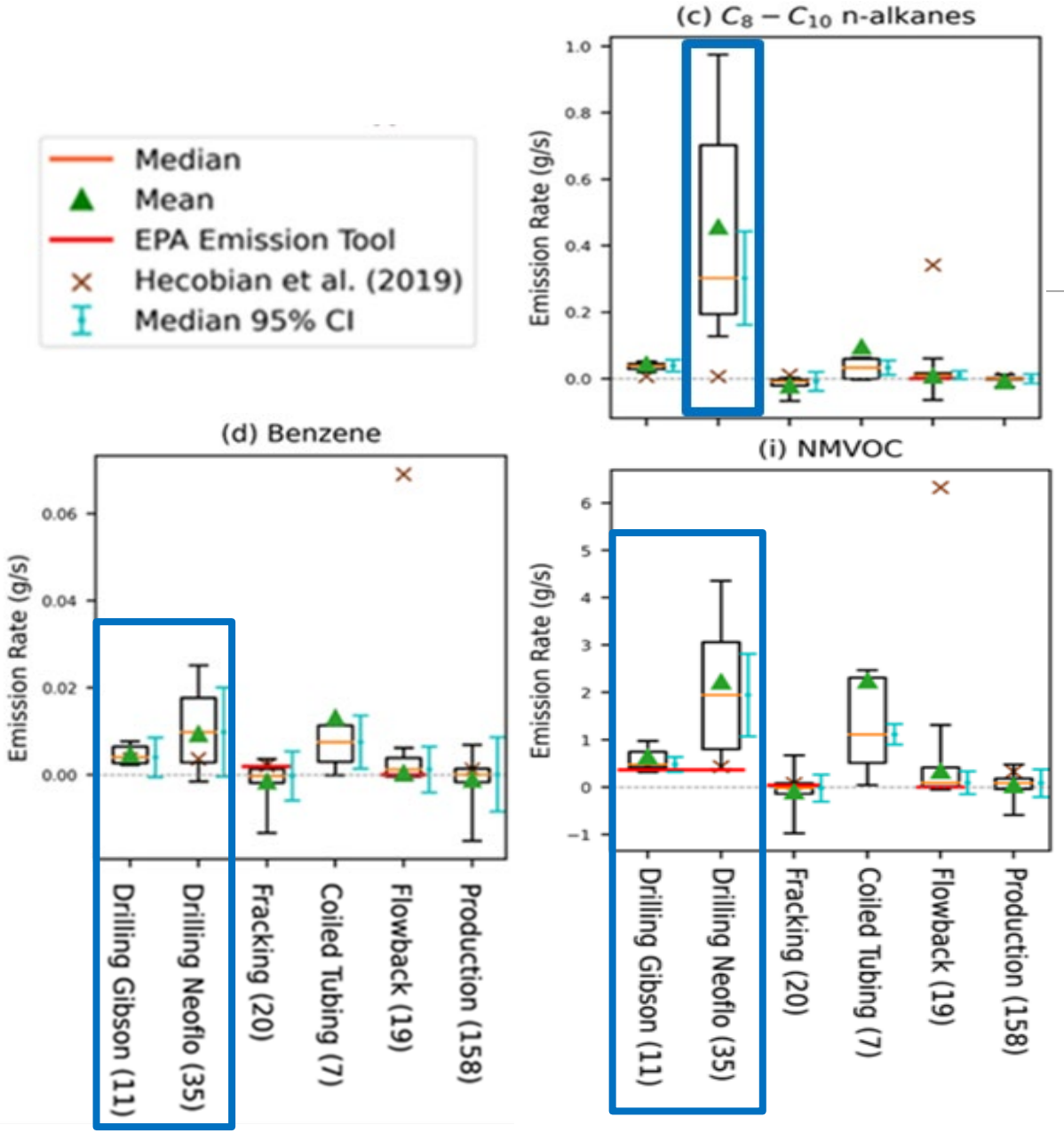

Constraining UOGD VOC emission rates

- **Updated estimates for drilling mud volatilization**
  - **including synthetic Neoflo**
  - **Higher than EPA tool and Hecobian et al.**
- First emission estimates for coil tubing/millout operations
- >95% reduction in average VOC and benzene emissions from flowback using closed-loop, tankless systems vs. Hecobian et al. green completions
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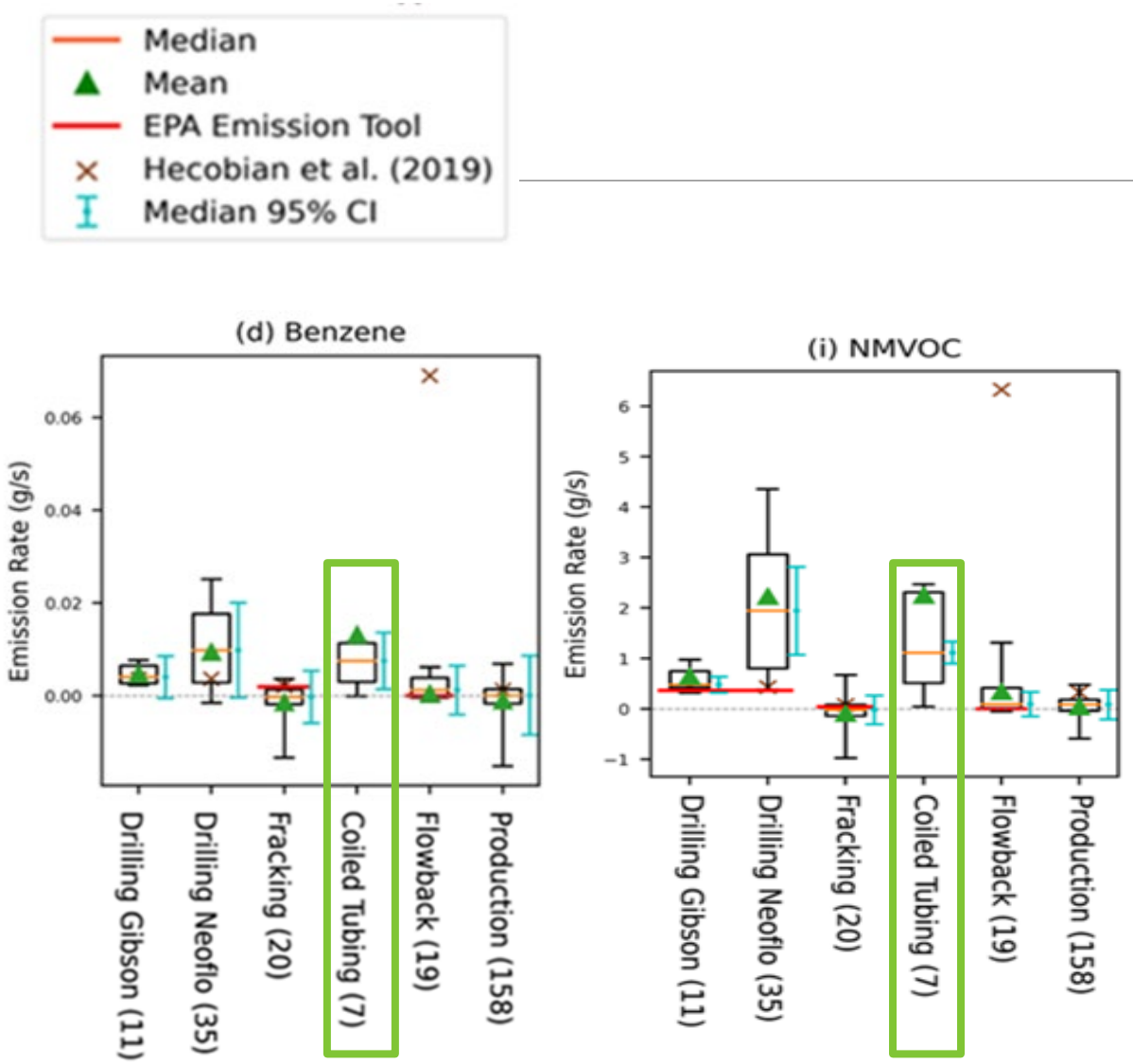

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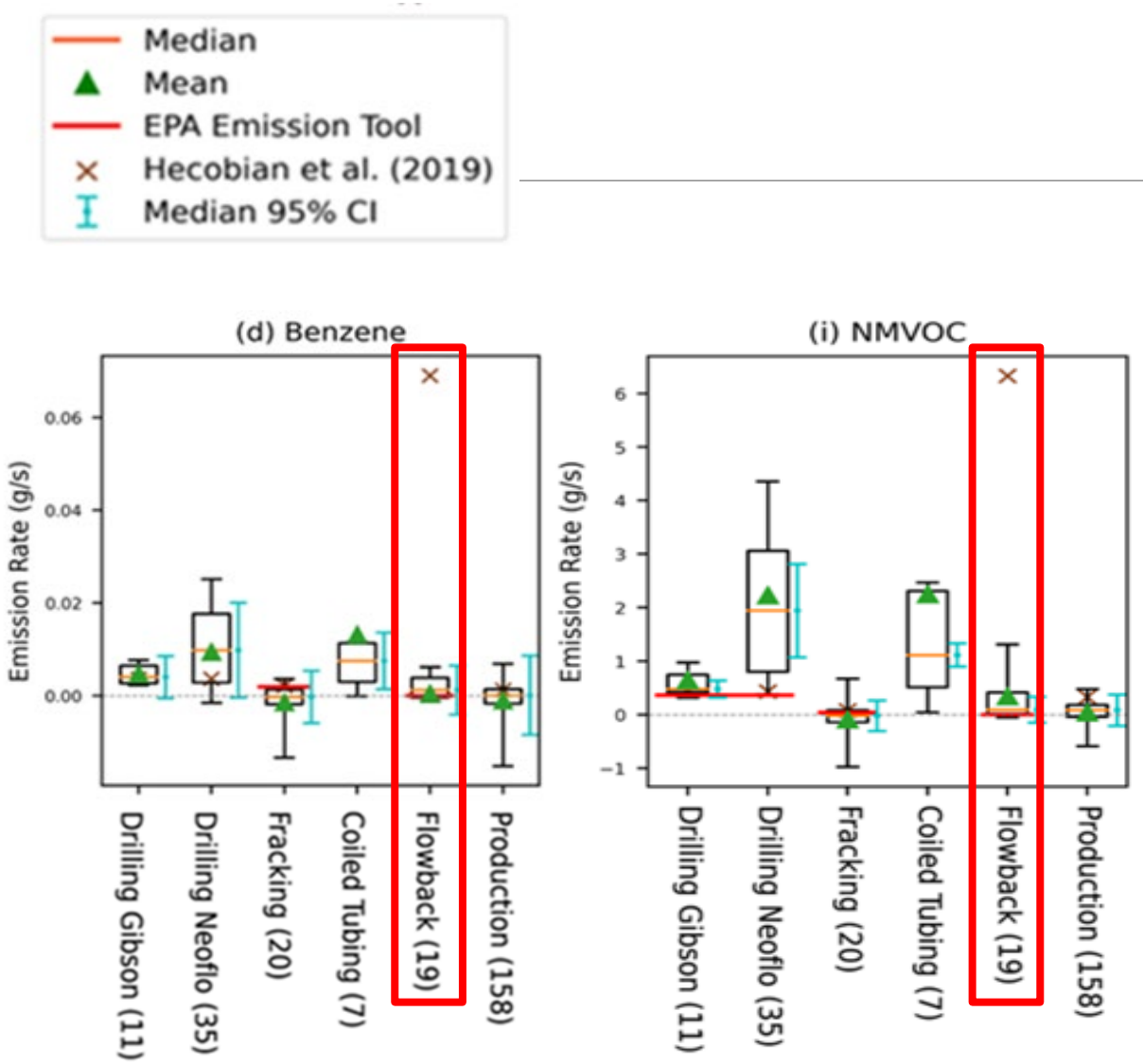

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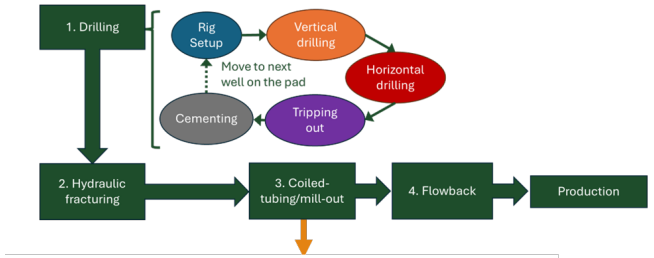
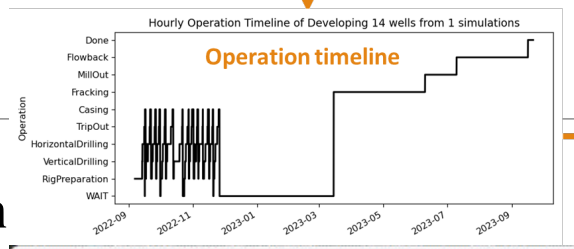
Development of model Graphical User Interface (GUI)

- **A GUI has been created to enhance accessibility in policymaking and research related to environmental health:**
  - Created using Python 3 (PyQt5).
  - Also packaged as a standalone .exe file for Windows.
  - Inputs file are Excel sheets for easy access, except for AERMOD outputs.
  - Evaluated model performance with DJ air monitoring results.





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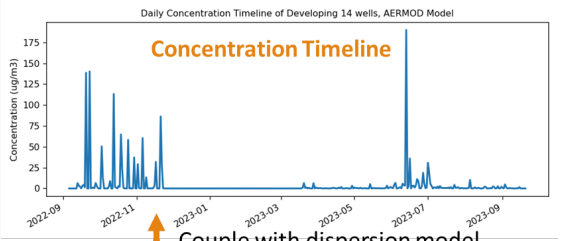

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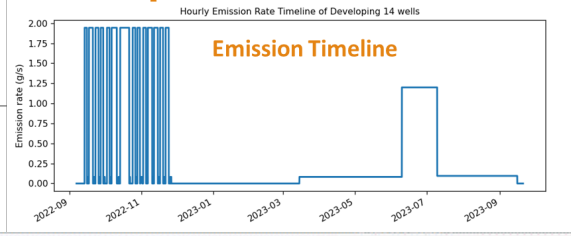
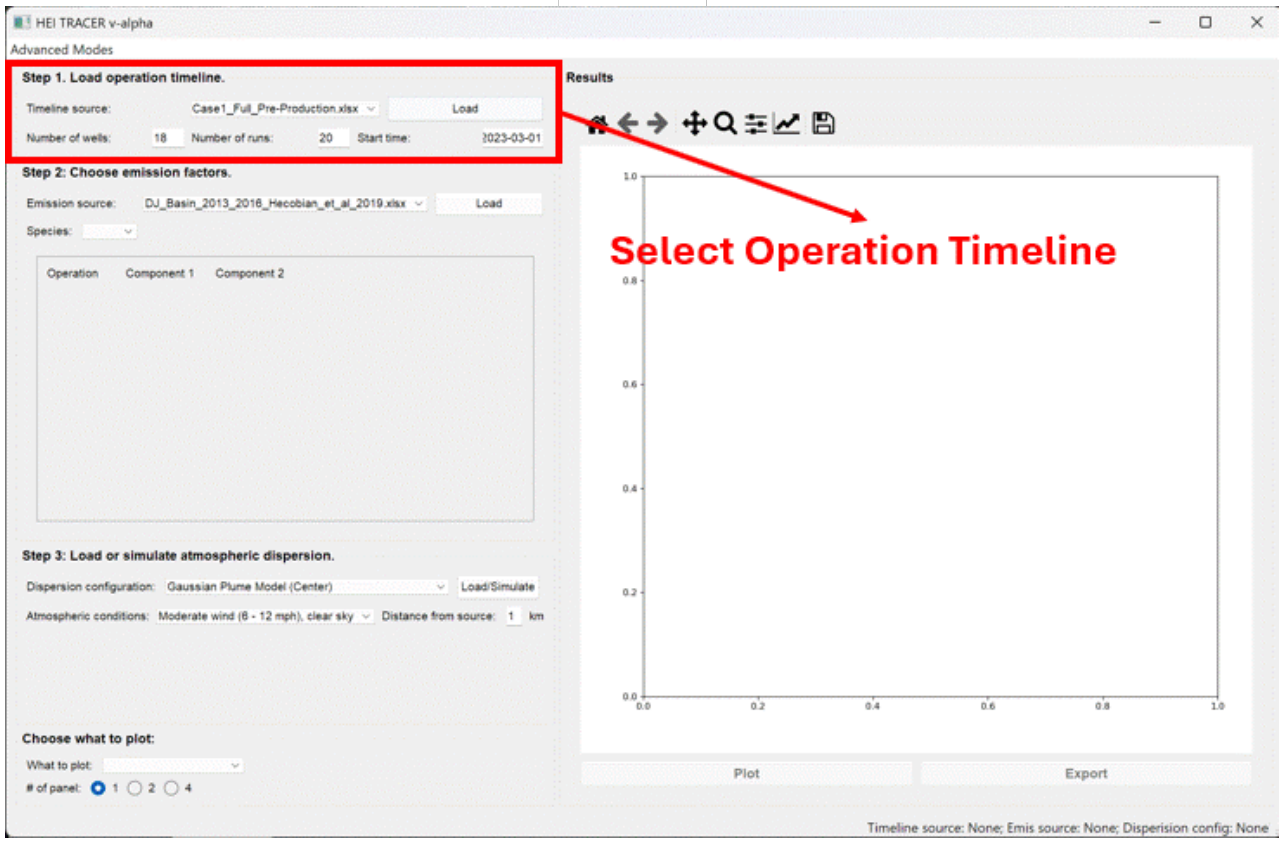




Operation timelines

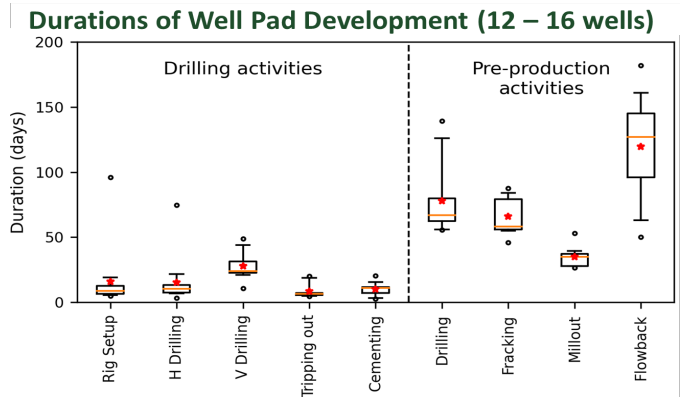
Detail operation logs from operators.

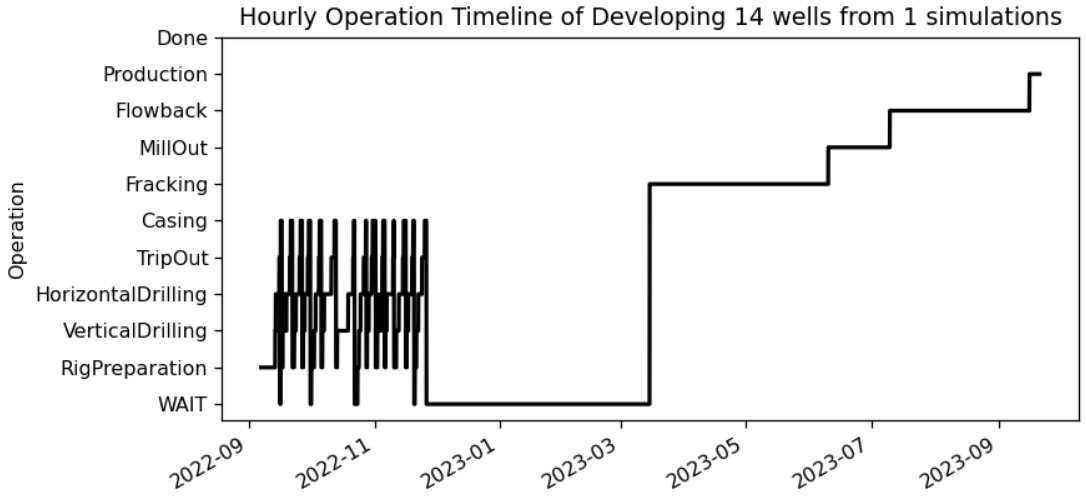
Start Time	End Time	Operation
2022/09/06 18:00	2022/09/12 06:00	Move/Skid - Nipple Up
2022/09/12 06:00	2022/09/13 14:30	BOP Test
2022/09/13 14:30	2022/09/13 15:30	Drill VS
2022/09/13 15:30	2022/09/13 20:30	Drill Curve
2022/09/13 20:30	2022/09/15 13:15	Drill Hz
2022/09/15 13:15	2022/09/16 01:00	Trip out & Circulate
2022/09/16 06:00	2022/09/16 22:00	Case & Cement

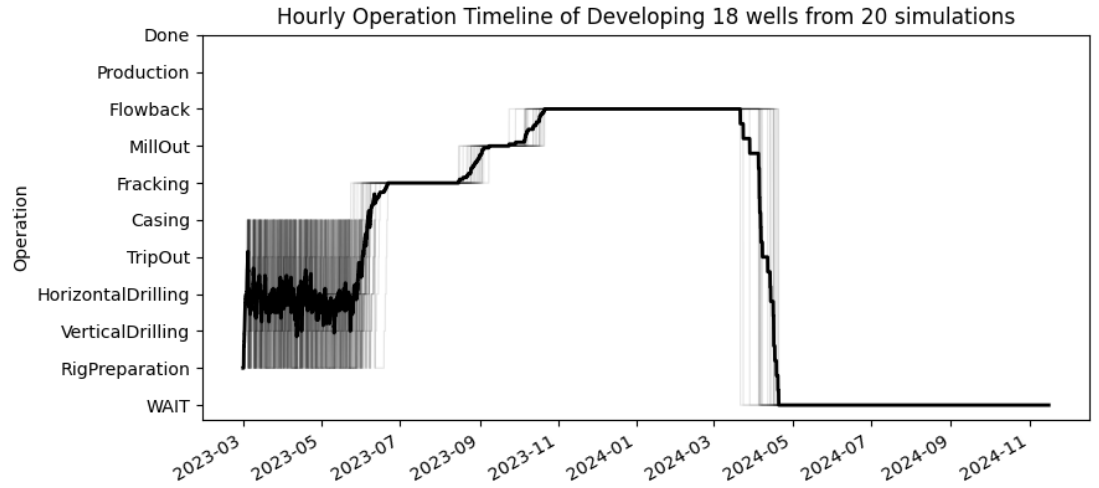
Start Time	End Time	Operation
2023/03/15 00:00	2023/06/09 23:59	Fracking
2023/06/10 00:00	2023/07/09 23:59	MillOut
2023/07/10 00:00	2023/09/15 23:59	Flowback
2023/09/15 00:00	2023/03/31 23:59	Production

Simulate operation timelines (MAES):

- Monte Carlo approach;
- Duration distributions are from real-world pad development timelines.



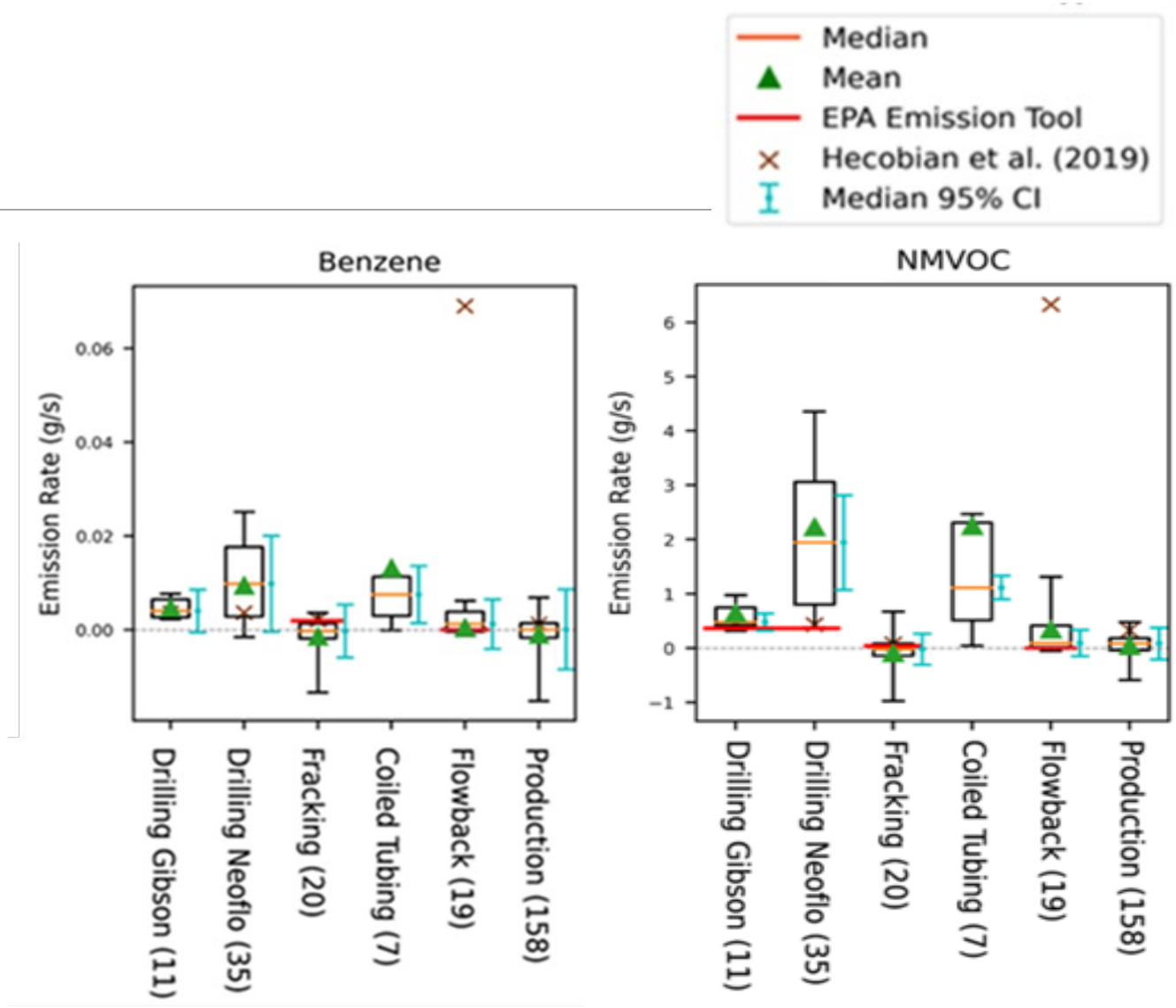




Emission factors

- The GUI comes with three sets of emission factors, offering options for various practices.
- Users can adjust the emission factors directly.

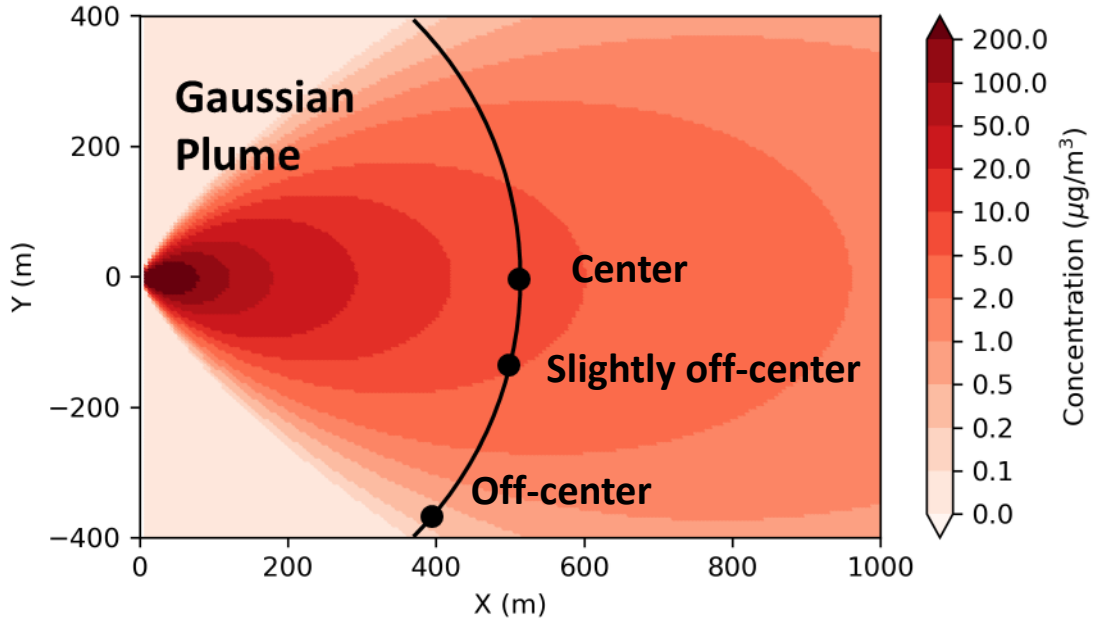
Operation	Component 1	Component 2	Emis Rate (g/s)
RigPreparation	Electric		0.000
VerticalDrilling	Electric	Drilling Mud Gibson	0.430
HorizontalDrilling	Electric	Drilling Mud Gibson	0.430
TripOut	Electric	Clean pipe	0.000
Casing	Diesel Engine		0.082
Fracking	Diesel Engine		0.082
MillOut	Diesel Engine	Uncontrolled Vent	0.082
Flowback	Green with Tanks		6.330
Production	Normal Production		0.330



Atmospheric dispersion

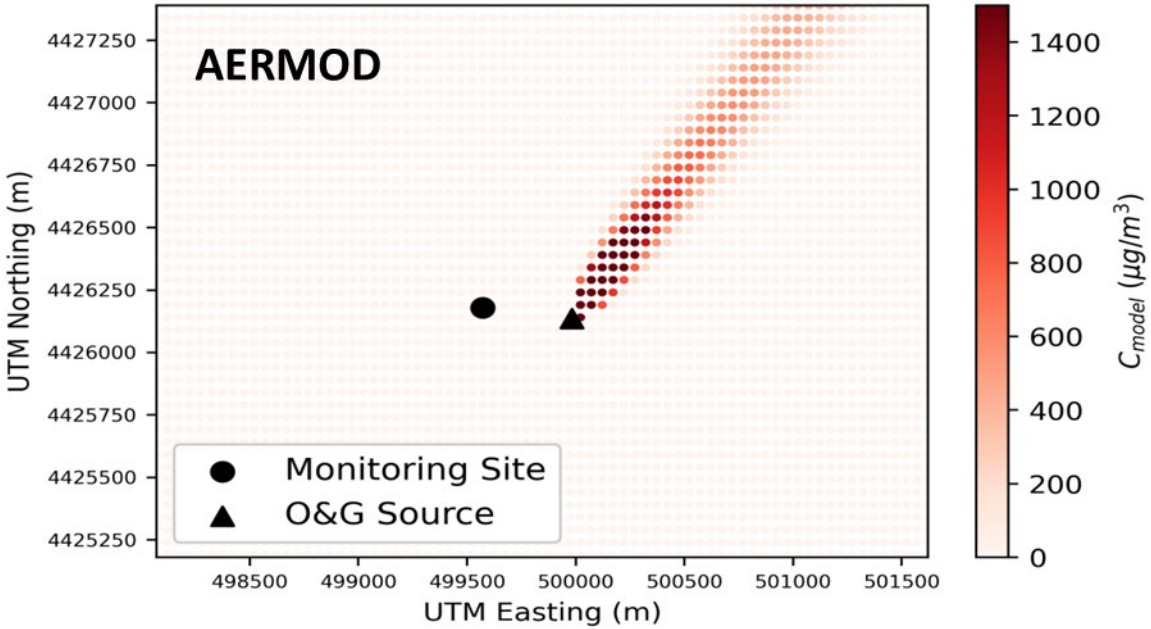
Gaussian plume model:

- Users can modify atmospheric settings and receptor positions (distance/height).
- Three preset locations are included for convenience.



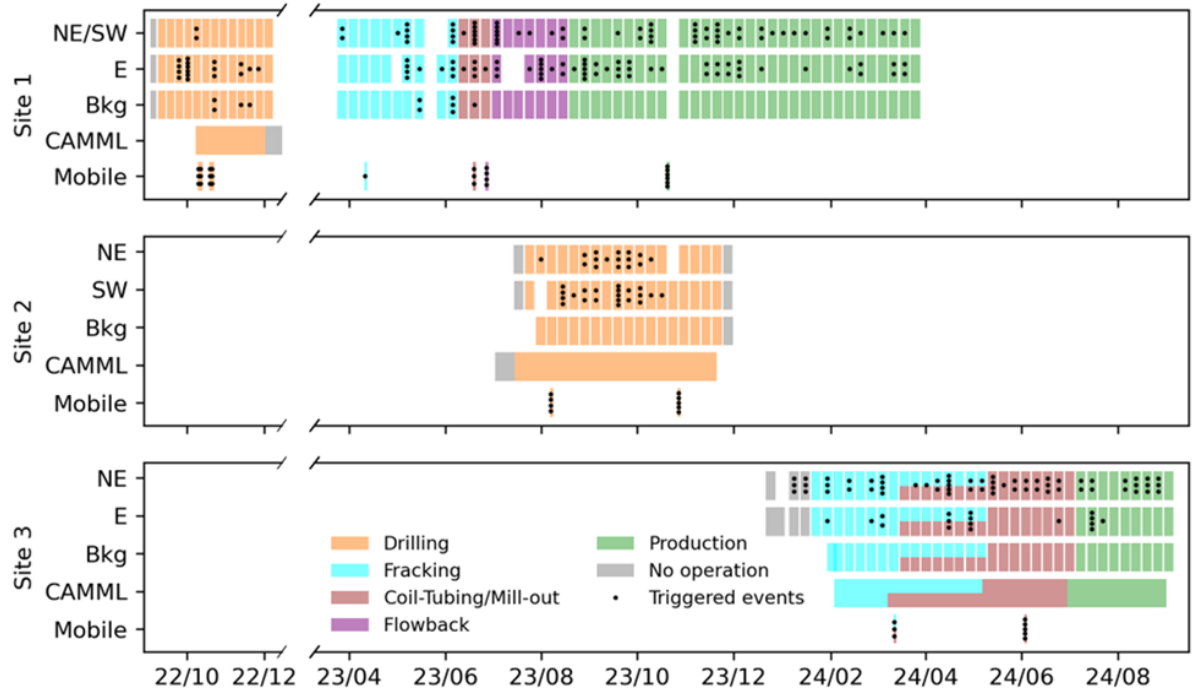
AERMOD model:

- The GUI can read AERMOD outputs directly.



Model evaluation through air monitoring

Observation and UOGD timelines:

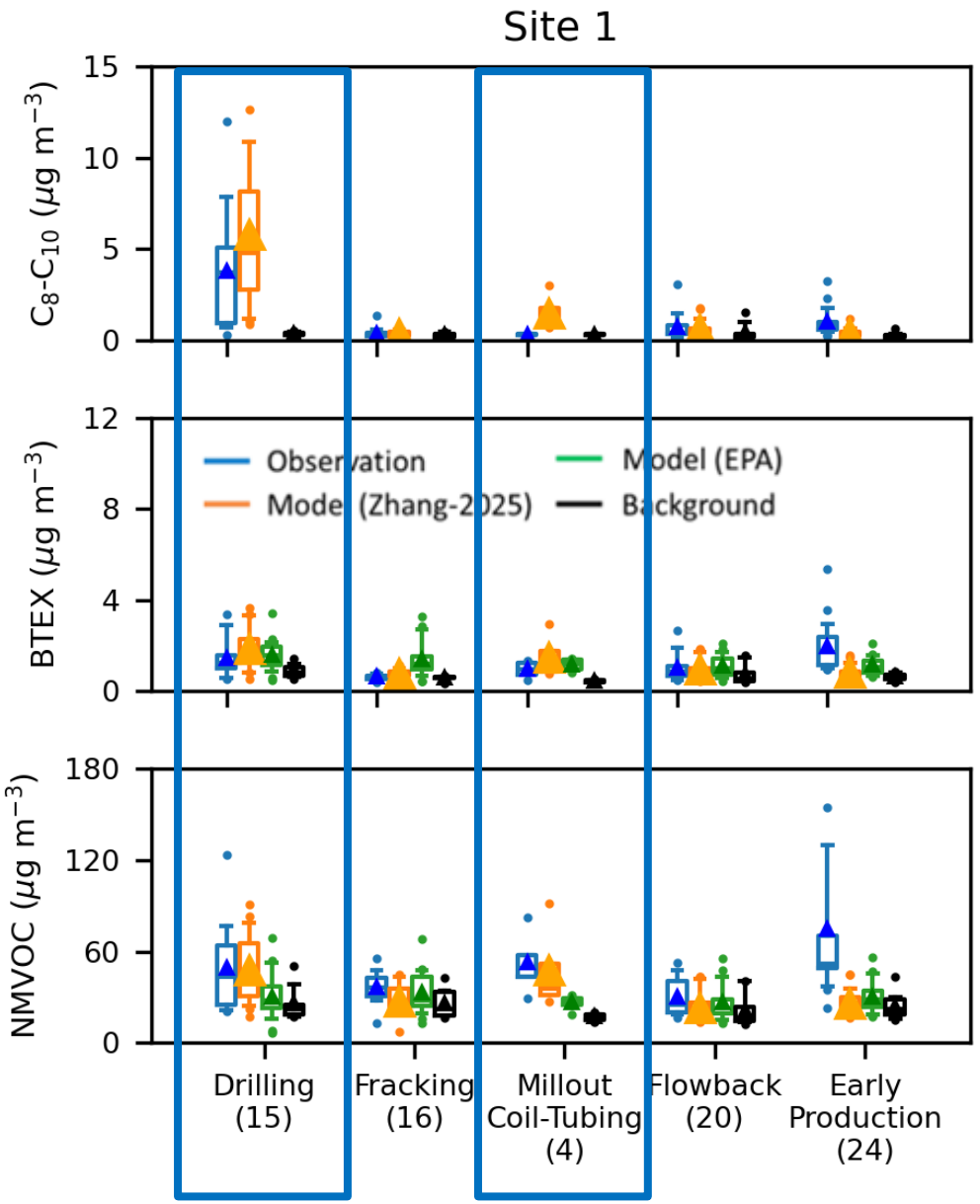


Model configuration:

- Detailed operation timelines;
- Inverse-modeled emission rates (Zhang-2025) and EPA Emission Tool;
- AERMOD simulations for monitoring locations.

Evaluation: Weekly VOC Concentrations

- **Updated emission factors better represent drilling and coil-tubing emissions**
  - **Including $C_8 – C_{10}$ n-alkanes from drilling muds**
  - **Higher than EPA tool during drilling and coil-tubing**
- VOC concentrations during early production show large variability
  - Underestimated by both Zhang-2025 and EPA Tool at site 1; but overestimated by EPA Tool at 3 (not shown).
  - Changing practices need further investigation



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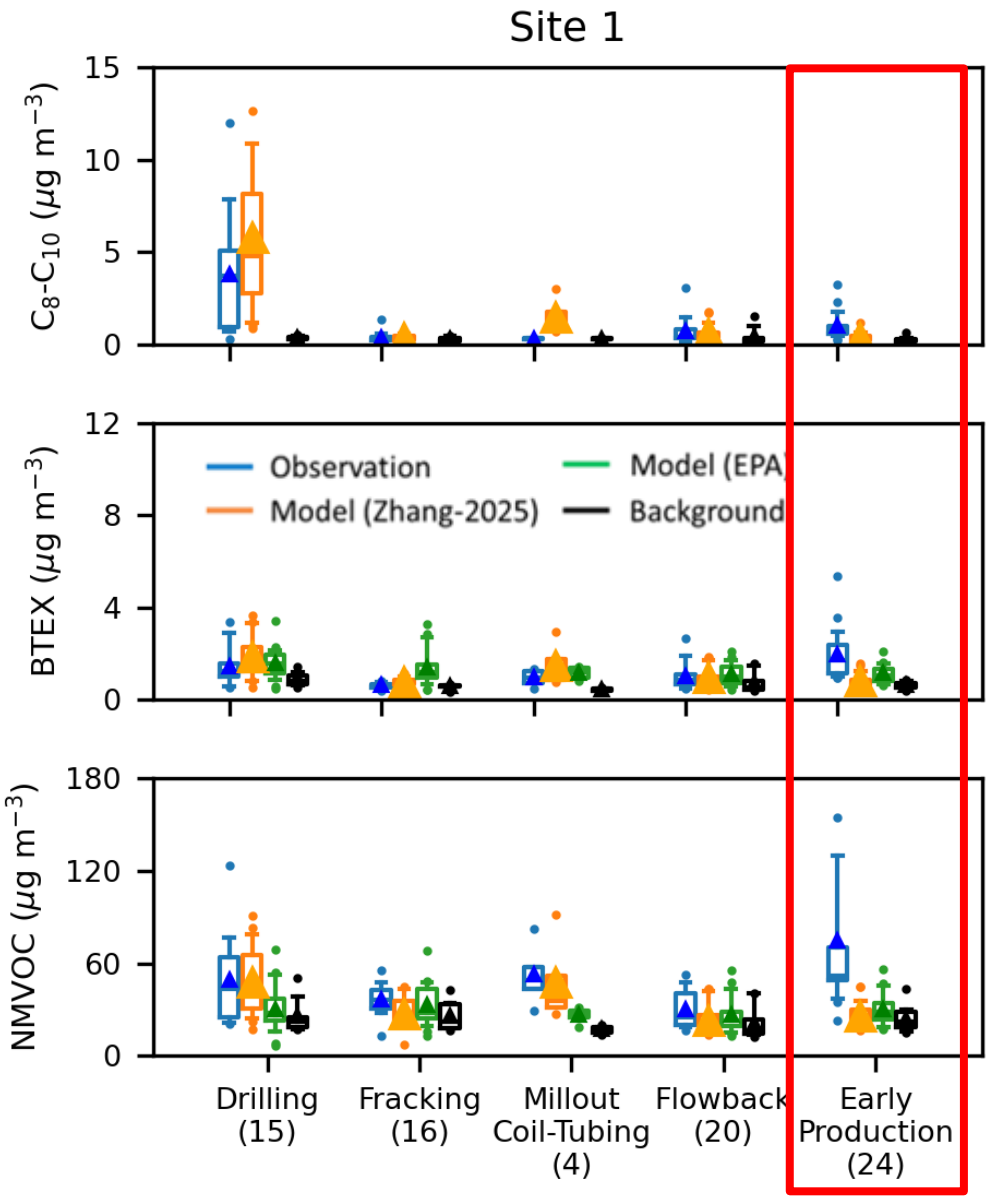

Evaluation: benzene hourly exceedance (9 ppbv)

- The low early production emission rate of Zhang-2025 leads to the underestimation of benzene exceedance events.
- EPA Emission Tool significantly overestimates the number of exceedance events during early production.

	Site 1 Drilling	Site 2 Drilling	Site 3 Fracking	Site 3 Fracking & Coil-Tubing	Site 3 Coil-Tubing & Production	Site 3 Early Production
CAMML observations	1	0	0	0	**8**	**4**
Model with Zhang-2025 emission rates	0	0	0	1	**5**	**0**
Model with EPA emission rates	0	0	0	0	**5**	**19**

Study highlights - modeling

- New TRACER UOGD pre-production model. Enables stakeholders to
  - Predict air quality impacts and their timing during specific operational phases
  - Evaluate air quality benefits of best management practices such as
    - drill rig electrification
    - drilling mud choice
    - closed-loop/tankless fluids handling
    - altering schedule to different season

- Recent DJ Basin UOGD pre-production activities studied to improve model emission rate inputs for current UOGD practices
- Reasonable performance for DJ Basin UOGD pre-production activities but needs to be tested in other basins